

**Maternal Body Mass Index, Neighborhood Characteristics and Early
Childhood Obesity**

By

Matthew A. Goldshore, MD, MPH

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Abstract

Objective

Childhood obesity is a leading cause of morbidity among US children with nearly 1 in 10 children ages 2 - 5 with a BMI greater than the 95th percentile. Childhood obesity is associated with multiple comorbidities including early-onset type II diabetes, sleep apnea, mood disorders, social marginalization and bullying. Moreover, obese children are more likely to become obese adults. Maternal pre-pregnancy BMI is one gestational exposure consistently associated with offspring obesity. Neighborhood characteristics, including socioeconomic deprivation and food environment, represent shared maternal-child exposures which have also been associated with child obesity. The objective of this thesis was to evaluate the association between maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics and child BMI percentile at 5 years (aim 1) and BMI trajectory from 2 - 8 years (aim 2).

Methods

The study sample was drawn from the Delaware Mother and Baby Cohort (DMBC), a prospective cohort of 4,852 women who delivered at Christiana Care Health System (CCHS) in Newark, Delaware between January 1, 2004 and December 31, 2007; and who accessed pediatric care for their child through the Nemours Children's Health System (NCHS) at least once between January 1, 2004 and May 31, 2011. The DMBC was linked with Delaware birth certificates, the 2010 US Census and the Delaware Healthy Toolkit Food Resource Database. The primary dependent variables were age- and sex- standardized BMI percentile at age 5 (aim 1) and rate of change in BMI ($\text{kg/m}^2/\text{month}$) from 2 - 8 years (aim 2). The

main independent variables included maternal pre-pregnancy BMI, neighborhood socioeconomic deprivation and distance between mother's residence and closest healthy food outlet. Associations found in bivariable analyses informed multivariable modeling. Multivariable multinomial logistic regression was performed to identify the independent influence of maternal pre-pregnancy BMI, neighborhood food environment and census-tract socioeconomic deprivation on child BMI percentile at 5-years and BMI trajectory from 2 to 8 years after adjusting for other covariables. For all analyses, p-values < 0.05 were considered statistically significant. All analyses were performed using Stata/IC Version 13.0 and Comprehensive R Archive Network (R) Version 3.4.2. This study was approved by the Christiana Care Health System and University of Wisconsin - Madison Institutional Review Boards.

Results

A total of 3,101 (63.9%) of DMBC participants met inclusion criteria for aim 1 and 3,862 (79.6%) of DMBC participants met inclusion criteria for aim 2. The sample characteristics were similar for both study aims; one-quarter of DMBC women had a pre-pregnancy BMI ≥ 30 kg/m², one-quarter of dyads lived < 0.5 miles from the nearest healthy food outlet and 35% of participants resided in census-tracts with extreme socioeconomic deprivation. In multivariable models, maternal pre-pregnancy BMI was strongly associated with overweight and obesity at 5-years as well as steady and rapid gain BMI trajectory from 2 - 8 years old; it was not associated with a declining BMI trajectory. Children who resided in communities characterized by extreme socio-economic deprivation had significantly higher odds of obesity at 5-years than their counterparts in less deprived communities but proximity to healthy food outlets was not associated with child BMI at 5-years.

Neither census-tract socio-economic deprivation nor neighborhood food environment was associated with child BMI trajectory.

Conclusions

The odds of childhood obesity at 5-years and steady or rapid childhood BMI gain from 2 - 8 years were independently associated with maternal pre-pregnancy obesity after adjusting for maternal socio-demographic, pre-pregnancy health, pregnancy health and community characteristics. BMI at age 5 but not BMI trajectory was independently associated with neighborhood census-tract socioeconomic deprivation. Local food environment was not associated with child BMI or BMI trajectory. Children of obese women carry the highest odds of obesity in early childhood. Additional research is needed to better understand the association between neighborhood characteristics and early childhood BMI among offspring of obese and non-obese mothers.

Advisors: Cynthia S. Minkovitz, MD, MPP and Donna Strobino, PhD

Committee of Thesis Readers

Committee Members

Cynthia Minkovitz, MD, MPP (Advisor)

William H. Gates, Sr. Professor and Chair

Department of Population, Family and Reproductive Health, Johns Hopkins
Bloomberg School of Public Health

Professor

Department of Pediatrics, Johns Hopkins School of Medicine

Donna Strobino, PhD (Advisor)

Professor and Vice Chair

Department of Population, Family and Reproductive Health, Johns Hopkins
Bloomberg School of Public Health

Pamela Donohue, ScD, MS (Committee chair)

Associate Professor

Department of Pediatrics, Johns Hopkins School of Medicine

Lawrence Cheskin, MD

Associate Professor

Department of Health, Behavior and Society, Johns Hopkins Bloomberg
School of Public Health

Associate Professor

Department of Medicine, Johns Hopkins School of Medicine

Janice Henderson, MD, MA, MFA

Assistant Professor

Department of Gynecology and Obstetrics, Johns Hopkins School of
Medicine

Alternate Committee Members

Mary Elizabeth Hughes, PhD

Associate Scientist

Department of Population, Family and Reproductive Health, Johns Hopkins
Bloomberg School of Public Health

Joanne Katz, ScD

Professor

Department of International Health, Johns Hopkins Bloomberg School of
Public Health

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I have always been interested in how maternal disease impacts child health. I find it unjust that socioeconomically deprived women and children are more at risk for disease. I believe that the relation between maternal and child disease is both a result of biological influence and social context. These are the principles that guide my research.

I am grateful for the opportunity to study at the Johns Hopkins Bloomberg School of Public Health. Thank you, Drs. Cynthia Minkovitz and Donna Strobino, my co-advisors, for supporting my research interests and guiding my scholarship. Dr. Deborah Ehrenthal, thank you for creating the Delaware Mother and Baby Cohort and embracing my work on this project.¹

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1. Introduction

Background

Obesity is a leading cause of morbidity among young children in the United States. Nearly 1 in 10 United States children (8.9%) ages 2-5 had a body mass index (BMI) greater than the 95th percentile for age, and 1.7% had a BMI greater than the 120th percentile (extreme obesity) for age in 2011-2014 (Ogden, 2016). Obesity in children is associated with morbidities such as glucose intolerance (Invitti, 2003), early-onset type II diabetes (Hannon, 2005), hypertension (Gortmaker, 1987; Gupta, 1990; Sorof, 2002) and sleep apnea (Dietz, 1998); emotional health concerns such as low self-esteem (Franklin, 2006; French, 1995; Strauss, 2000), body dysmorphia (Must, 1999; Schwartz, 2004) and mood disorders (Daniels, 2006; Goodman, 2002; Horton, 2008); and social problems such as stigma (Andreyeva, 2008; Puhl, 2008; Schwartz, 2003), bullying and social marginalization (Griffiths, 2006; Janssen, 2004; Puhl, 2008). In addition, there are significant long-term effects; obese children are more likely to become obese adults and to experience heart disease, diabetes and certain cancers as adults (Dietz, 1998; Ebbeling, 2002; Must, 1999; Strauss, 2000).

While the prevalence of obesity in children 2-5 plateaued from a three-fold increase from 1988 to 2010 (Ogden 2014; Ogden, 2016), obesity and extreme obesity in all children 2-19 years old continues to rise. In addition, the condition continues to disproportionately affect minority and socioeconomically disadvantaged children (Wang, 2007; Ogden, 2016; Hales, 2017). Among non-Hispanic black and Hispanic children ages 2-5 years, obesity prevalence was estimated to be 10.4% (95% CI: 7.5% - 14.0%) and 15.6% (95% CI: 12.5% - 19.2%) in 2011 - 2014, respectively, while the prevalence for white children ages 2-5 was 5.2%

(95% CI: 3.1% - 8.3%) (Ogden, 2016; Hales, 2017). The disparity in obesity prevalence was more evident in children 6-11 for whom 21.4% (95% CI: 17.5% - 25.8%) of non-Hispanic black and 25.0% (95% CI: 22.0% - 28.1%) of Hispanic children had an age- and sex- standardized BMI greater than or equal to the 95th percentile compared to 13.6% (95% CI: 9.8% - 18.3%) of their non-Hispanic white counterparts (Ogden, 2016; Hales, 2017).

The Developmental Origins of Health and Disease hypothesis posits that early life environmental exposures, including in the pre-conceptual and gestational periods, have long term effects on health. Given the importance of sensitive periods of development, increased attention has been paid to modifiable maternal characteristics that impact the gestational environment as potential early intervention points to mitigate offspring disease risk. Maternal pre-pregnancy obesity is strongly associated with morbidity during the reproductive years and may contribute to the development of obesity in her offspring.

Between 2015 and 2016, over one-third of reproductive age women in the United States were obese (36.5%). Like children, there is considerable disparity in BMI by race and ethnicity (Hales, 2017). Among non-Hispanic black and Hispanic women ages 20-39 years, obesity prevalence was estimated to be 54.8% and 50.6%, respectively, while the prevalence for white women, ages 20-39, was 38.0% (Hales, 2017).

Obesity places women at higher risk for multiple chronic health conditions including cardiovascular disease (hypertension and coronary artery disease), endocrine disease (polycystic ovarian syndrome, glucose resistance and diabetes), cerebrovascular disease (stroke) and renal disease (Azarbad, 2010; Flegal, 2007; Khairy, 2017; Malnick, 2006). Overweight and obese women are more likely to develop pregnancy-related complications including gestational diabetes, pregnancy induced

hypertension, preeclampsia and the syndrome of hemolysis, elevated liver enzymes and low platelet count (HELLP) (Catalano, 2017). In addition, obese women are more likely to have an operative vaginal (forceps and vacuum) or cesarean delivery compared to their normal weight counterparts (Abenhaim, 2007; Kaiser, 2007; Kaiser, 2001).

Evidence from observational studies supports an association between maternal pre-pregnancy BMI and intrauterine fetal growth. Obese women have higher odds of delivering macrosomic ($\geq 4,500$ g regardless of the gestational age) and large-for-gestational-age ($\geq 90^{\text{th}}$ percentile) newborns than normal or overweight women (Catalano, 2006; Ehrenberg, 2004). High birth weight ($\geq 4,000$ g) infants as well as infants with accelerated early childhood growth are more likely to become obese children (Curhan, 1996; Oken, 2003; Taveras, 2011).

Extensive observational research supports a direct association between maternal and child obesity after adjusting for infant birth weight (Branum, 2011; Guillaume, 1995; Ludwig, 2013; Oken, 2007; Salsberry, 2007; Whitaker, 2004; Yu, 2013) though the mechanism for this association remains unclear. The link between maternal and child obesity was originally believed to be solely the result of genetic influence; however, new research hypothesizes that the intrauterine environment may confer higher offspring body weight through epigenetic, placental and/or hormonal mediators (Catalano, 2017). Though pre-pregnancy BMI may directly influence the intrauterine obesogenic fetal milieu through a variety of mechanisms, shared postnatal exposures such as diet/food environment, physical activity and socioeconomic status also influence the correlation between maternal and child weight status.

Neighborhood attributes represent shared exposures for mother and child. Widespread research has been conducted to determine if neighborhood characteristics are associated with risk for and

resiliency against childhood obesity. For example, density of convenience stores (Borradaile, 2009; Galvez, 2009; Grafova, 2008; Jennings, 2011; Oreskovic, 2009) and level of neighborhood criminal activity (Salois, 2012) have been shown to be directly associated with higher obesity prevalence among children. In addition, community wealth may be indirectly related to childhood obesity as children who live in neighborhoods characterized by social and economic deprivation experience increased risk of obesity compared to their counterparts in less deprived communities (Nelson, 2006; Singh, 2008). Neighborhood factors may also affect obesity risk in women (Alvarado, 2016; Carroll, 2013; Lippert, 2016; Robert, 2004).

It is challenging to understand the impact of neighborhood socioeconomic environment on childhood obesity without consideration of more proximal maternal characteristics. Only limited research has simultaneously evaluated the relation of neighborhood characteristics and maternal factors with childhood obesity. Ecological systems theory provides a framework to study the relation between individual characteristics and the influence of the community and social context in which they live (Bronfenbrenner, 1979).

Conceptual framework

The current study used data from the Delaware Mother and Baby Cohort (DMBC) to evaluate the association of maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics with child BMI percentile at 5 years and BMI trajectory from 2 – 8 years. The conceptual framework guiding this work is depicted in **Figure 1-1** and is informed by ecological systems theory (Bronfenbrenner, 2009), the eco-social model (Glass, 2006), the social determinants of health inequalities (Marmot, 2005) and other models specifically developed to

address the impact of neighborhood factors on women and children (Surkan, 2012). Fundamental to this research is the assumption that there are multiple influences on childhood obesity including factors at the intrapersonal (child), interpersonal (maternal and familial), organizational, community and public policy levels, and that these influences may interact in their impact on obesity (Sallis, 2008).

Maternal health characteristics (pre-pregnancy weight status, gestational and pre-gestational diabetes) contribute to early childhood obesity as do other maternal/familial demographic characteristics (maternal age, insurance status, marital status, education). Maternal health is determined by its own set of multilevel modifiable and non-modifiable risk factors, all of which may impact child health. As a result, maternal health characteristics are depicted as one level in the conceptual model nested between child factors and maternal/familial demographic characteristic. Neighborhood deprivation and food environment, more distal factors, represent shared community exposures to women and children; they are depicted outside the maternal and child factors half-circles.

Specific aims

The DMBC provides longitudinal mother and child paired data for women who delivered at a large tertiary care center in Delaware from December 2004 to December 2007 and who accessed pediatric care for their child through a multi-specialty pediatrics practice in the State from January 2004 until May 2011. The DMBC was linked to birth certificate, United States Census (tract-level) and geocoded Delaware food outlet data. This unique data set allowed for exploration of the role of neighborhood exposures on maternal obesity, as well as to evaluate the role of maternal characteristics and neighborhood

exposures on child BMI and BMI trajectory. Two specific aims were evaluated using the DMBC.

Specific aim 1 investigated the relation of maternal pre-pregnancy BMI and neighborhood exposures with weight status of DMBC 5-year-old children. The objective of this aim was to assess the association of maternal pre-pregnancy BMI and neighborhood exposures, including census-tract deprivation and neighborhood food environment, with child weight status among DMBC 5-year-old children.

Specific aim 2 investigated the relation of maternal pre-pregnancy BMI and neighborhood exposures on the BMI trajectories of DMBC children from 2-8 years old. Two objectives were evaluated, to:

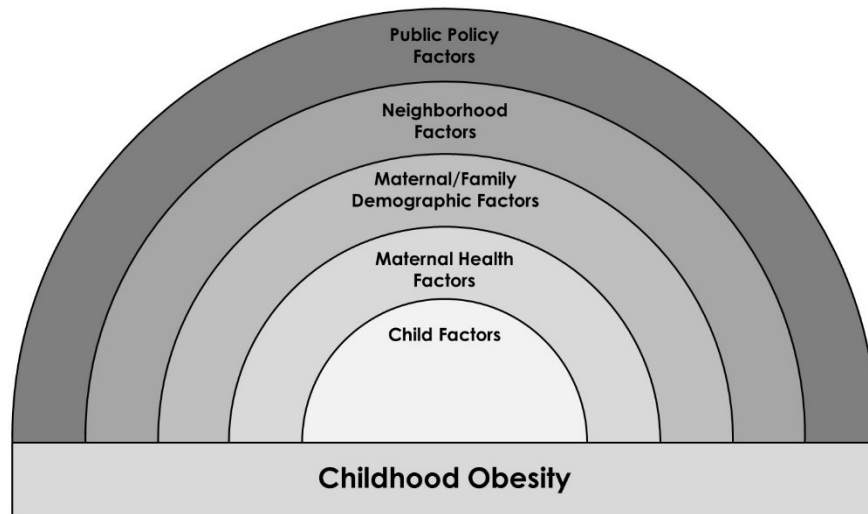
- (1) describe the BMI trajectories of DMBC children from 2 - 8 years old, and
- (2) assess the association of maternal pre-pregnancy BMI and neighborhood exposures, including census-tract deprivation and neighborhood food environment, on the BMI trajectories of DMBC children from 2 - 8 years old.

Organization of the dissertation

This dissertation is organized in five chapters. This chapter introduced the research and presented the conceptual framework and specific aims of the study. Chapter 2 provides a review of the literature on the associations between neighborhood environment, maternal pre-pregnancy BMI and child BMI. Chapter 3 describes the methodological approach including details about the study sample, hypotheses, and variables as well as the analysis for each aim. Chapter 4 presents the results for each study aim. Chapter 5 summarizes the study findings, explores the strengths and limitations of the work as

well as the public health significance and implications for research, clinical and public health practice.

Figure 1-1: Conceptual framework of dissertation



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2. Literature review

The causes of obesity are multi-factorial and vary across the life course. Though obesity is a result of an imbalance between caloric intake and energy expenditure, the difference between intake and output alone fails to account for myriad other characteristics that impact weight status. These range from genetic predisposition to social influences impacting dietary and exercise practices. In addition, the factors which contribute to obesity early in life may have less of an effect on risk of obesity in adulthood. Maternal characteristics, such as pre-pregnancy BMI, likely contribute more directly to obesity risk in childhood than later in life when dietary practices and social influences may have a greater effect. Similarly, risk factors that contribute to maternal pre-pregnancy obesity are time-dependent as parity, inter-pregnancy interval and appropriateness of weight gain in previous pregnancies may play a greater role in obesity risk in the reproductive period than during other times in a woman's life.

Neighborhood exposures known to influence obesity risk, such as socioeconomic deprivation and food environment, represent shared mother and child experiences that may influence both childhood obesity as well as maternal pre-pregnancy BMI. Because the impact of these neighborhood exposures on children may act, in part, through household food purchasing, dietary practices and maternal exercise behaviors, their independent impact on obesity risk is difficult to disentangle. As a result, it is important to understand the relation of neighborhood characteristics with maternal pre-pregnancy obesity as well as with childhood obesity and body mass index (BMI) trajectory to identify whether these variables have an impact on the relation between maternal and child obesity.

The purpose of this literature review is to describe, critically evaluate and identify gaps in understanding of neighborhood determinants of maternal obesity, childhood overweight/obesity and early childhood BMI trajectory. Special attention is paid to literature regarding the role of socioeconomic deprivation and neighborhood food environment on obesity risk in early to middle childhood (Copple, 2009). The first section of this review provides a brief overview of the literature on determinants of maternal pre-pregnancy obesity. The second section focuses on maternal and neighborhood determinants of childhood obesity and BMI and weight gain trajectories. This chapter concludes with considerations for additional research to address knowledge gaps about these relations.

Measurement and determinants of maternal obesity

Understanding the research on maternal pre-pregnancy obesity is challenging due to variability in its measurement. The optimal measure of maternal pre-pregnancy obesity would be based on anthropometric data accurately collected immediately before conception; however, these data are seldom available. Most study data are obtained from medical records, and only a small subset of women visit their health care provider in the days just prior to becoming pregnant. As a result, proxy measures for maternal pre-pregnancy obesity often include self-reported pre-pregnancy height and weight or anthropometric measurements documented at the first prenatal visit to calculate body mass index (BMI).

Pre-pregnancy obesity is defined similarly to that for other adult populations for whom $BMI \geq 30 \text{ kg/m}^2$ is considered obese. A more granular classification of obesity, released by the World Health Organization (WHO) in 2000, has been commonly used as the health effects of different levels of obesity have become more evident. **Table**

2-1 shows the classification of BMI proposed by the WHO. Based on this classification, overweight is categorized as BMI between 25.0 – 29.9 kg/m² and obesity as BMI \geq 30 kg/m², which is further subdivided into three groups: class I 30.0 – 34.9 kg/m², class II 35.0 – 39.9 kg/m² and class III \geq 40 kg/m².

Critics of self-reported pre-pregnancy weight note that women may choose to under- or over-estimate their pre-pregnancy BMI for a variety of reasons. Some posit that self-reported pre-pregnancy BMI is flawed because the social stigma surrounding obesity results in underreporting of weight status among reproductive age women, regardless of pregnancy status (Holland, 2013). It is also possible that self-reported pre-pregnancy weight results in a non-directional misclassification as increased anticipatory guidance for appropriate weight gain in pregnancy among obstetricians may result in women overestimating their pre-pregnancy weight to artificially deflate gestational weight gain, irrespective of pre-pregnancy BMI. Though there may be some misclassification that results from social desirability bias, multiple studies have shown high concordance between self-reported and measured pre-pregnancy BMI.

In a large retrospective cohort of almost 7,500 women who delivered at a large academic medical center between 2011 and 2014, pre-pregnancy BMI categorized by self-report and measured weight were concordant in 85% of women. Multiparous women were more likely to underreport their pre-pregnancy BMI as compared to primiparous women; however, there was no difference in concordance by maternal age, race/ethnicity, marital status, or number of gestations (Bannon, 2017).

In another study of a subset of 170 women included in the Project VIVA cohort, an ongoing prospective cohort of pregnant women and children in Massachusetts, high correlation ($r = 0.99$) between self-

reported and measured pre-pregnancy weight was reported. In this validation study, women's reports of pre-pregnancy weight were obtained in the first trimester and compared to a documented weight abstracted from the electronic medical record within three months of the last menstrual period. Among study participants, the mean underreporting of 1 pound did not differ by race/ethnicity, gestational age at study enrollment or by weight (Oken, 2007). Although stigma regarding weight status may have the potential for misclassification, self-reported pre-pregnancy weight appears to be a valid and reliable measure of preconception weight status.

A different misclassification may result from the use of weight measured at the first prenatal visit as a proxy of pre-pregnancy weight. According to the 2009 Institute of Medicine Report *Weight Gain during Pregnancy: Reexamining the Guideline*, normal weight gain in the first trimester is between 1 - 4.5 pounds and 1 - 2 pounds per week for the second and third trimesters (Rasmussen, 2009). Because women access obstetric care at variable times during pregnancy, true pre-pregnancy weight and the weight measured at the first prenatal visit may differ substantially as gestational age increases. Although weight measured at the first prenatal visit may systematically overestimate true pre-pregnancy weight, it is also important to consider the potential underestimation that may result early in pregnancy due to morning sickness and intractable first trimester nausea.

In 2013, Holland et al compared the classification of pre-pregnancy body mass index (BMI) using self-reported pre-pregnancy weight versus weight measured at the first prenatal visit in a retrospective cohort of 307 women receiving care between April 2007 and March 2008 at an academic obstetrics practice in Massachusetts. All women included in this sample initiated prenatal care prior to 14 weeks

gestation and delivered singleton infants. In this sample, classification of pre-pregnancy BMI was concordant for 87% of women ($\kappa = 0.86$; 95% CI: 0.81, 0.90) (Holland, 2013). The author was unaware of any study in which weight documented at the first prenatal visit was compared to a pre-pregnancy weight measured within 1 year of conception. As a result, while self-reported pre-pregnancy weight and weight at the first prenatal visit was concordant in the work published by Holland et al, level of accuracy of the measure remains unclear.

Maternal demographic characteristics

Between 2011 and 2014, the prevalence of obesity among 20 - 39 year-old women in the United States was 36.5%, representing an almost 200% increase from 19.0% in the early 1960's (Hales, 2017). Data from a nine-state assessment of the Pregnancy Risk Assessment Monitoring System (PRAMS) support a similar trend in pre-pregnancy obesity from 13.0% in 1993 - 1994 to 22.0% in 2002 - 2003 (Kim, 2007). More recent vital statistics data support a continued increase in prevalence from 2002 with almost one in four women who delivered a live-born infant, defined as obese (24.8%) before becoming pregnant (Branum, 2016).

The 2003 birth certificate revision included new items to capture pre-pregnancy weight and height. As a result, the association between certain maternal demographic characteristics and maternal pre-pregnancy BMI are available for states that implemented the revised form. In a National Vital Statistics Report authored by Branum et al, pre-pregnancy BMI and associated demographic characteristics were reported for all women giving birth in 2014 for 47 states and the District of Columbia, the jurisdictions which implemented the 2003 U.S. Standard Certificate of Live Birth by January 1, 2014. Increased pre-pregnancy obesity was observed in women who were aged 40 - 54 (27.0%), non-

Hispanic black (34.8%), non-Hispanic American Indian and Alaska Native (36.4%), with partial college education without a degree (26.2% - 29.8%) and who were publicly insured (29.2%). Moreover, 30 of the 37 jurisdictions that adopted the new birth certificate in 2011 reported an increase in pre-pregnancy obesity from 2011 to 2014 (Branum, 2016).

Maternal pregnancy characteristics

Pregnancy related characteristics also may impact risk for pre-pregnancy obesity in successive births. Short inter-pregnancy intervals (Davis, 2014; Greene, 1988) and increased parity (Davis, 2014; Parker, 1993) have been consistently reported to increase postpartum weight retention and in turn, risk of obesity in subsequent pregnancies. In 2009, the Institute of Medicine (IOM) revised 1990 guidelines on appropriate weight gain in pregnancy in response to changes in the anthropometry of pregnant women over the previous two decades (Rasmussen, 2009). The revised gestational weight gain (GWG) guidelines aim to contribute to the health of reproductive age women and their children; increasing evidence supports the impact of excessive GWG on later life obesity, poor pregnancy outcomes (preeclampsia) and subsequent chronic disease risk (Rasmussen, 2009). Updated guidelines are based on pre-pregnancy BMI, and women who begin pregnancy overweight or obese are encouraged to minimize gestational weight gains **Table 2-2**.

Though the association between excess GWG on childhood obesity is less clear, there is a substantial body of evidence to support that GWG in excess of IOM recommendations increases risk of pre-pregnancy obesity in subsequent births (Amorin, 2007; Ashley-Martin, 2014; Chu, 2009; Kac, 2004; Lederman, 1993; Oken, 2009; Siega, 2004; Viswanathan, 2008). Multiple genetic (parental birth weight) (Pietilainen, 2001),

demographic (socioeconomic status) (Rothman, 2011), psychosocial (depression, body image) (Mehta, 2011; Strychar, 2000), lifestyle/behavioral (exercise, dietary practices and breastfeeding) (Baker, 2008; Harris, 2015; Stuebe, 2009) and cultural factors (cultural beliefs about appropriate weight gain) (Chasan, 2008; Hill, 2013) appear to contribute to excess GWG.

Although an important metric, GWG has measurement and conceptual challenges. GWG is typically operationalized as the difference between weight at delivery or at the last prenatal visit and pre-pregnancy or first prenatal weight. Regardless of calculation, GWG typically overestimates true weight gain during pregnancy as the relative contributions of placental mass, fetal weight, edema and adipose tissue not differentiated. Because of this imprecision, and the resultant part-whole correlation of weight gain with birth weight that results from the use of net GWG, this measure has been criticized as invalid and unreliable as a measure of maternal weight gain. While the intrinsic problems of GWG are noted, the measure has been associated with subsequent weight gain in multiparous women (Chu, 2009).

Neighborhood characteristics

This section reviews the literature evaluating the independent association between neighborhood characteristics and maternal weight status. Articles were included that operationalized maternal weight status as either maternal pre-pregnancy BMI or GWG. Both measures were included as limited research has specifically evaluated the impact of neighborhood characteristics on pre-pregnancy BMI. After a review of the research on these associations, the gaps in knowledge as well as the methodological limitations of this body of work are reviewed.

The built, socioeconomic and social environment may each impact maternal weight at the beginning of pregnancy as well as weight gain during gestation. Six studies were identified which evaluated the impact of neighborhoods on maternal pre-pregnancy BMI or GWG (Currie, 2010; Laraia, 2007; Mendez, 2014; Messer, 2012; Sellström, 2009; Vinikoor-Imler, 2011). Only two articles evaluated the association between neighborhood characteristics and maternal pre-pregnancy BMI (Mendez, 2014; Sellström, 2009). Five articles included excess GWG as the dependent variable (Currie, 2010; Mendez, 2014; Messer, 2012; Laraia, 2007; Vinikoor-Imler, 2011).

Sellström et al (2009) evaluated the association between neighborhood socioeconomic environment and maternal BMI at the first antenatal visit in a sample of 94,323 women in 586 Swedish neighborhoods surrounding Stockholm between 1992 and 2001. Neighborhood economic status was calculated from Statistics Sweden individual-level data for the two years prior to the infant's birth (1990 - 1998). Neighborhoods were defined according to natural geographic borders, and most had a population between 4,000 and 10,000 persons. Region income quintiles were calculated. The neighborhood income ratio was calculated by dividing the percentage of the population which fell into the lowest quintile by the percentage of the population which fell into the highest quintile. Neighborhood economic status was categorized using the neighborhood income ratio into affluent, medium and poor. The results indicated that 7% of the variation in obesity at the first antenatal visit was accounted for by this neighborhood variable. The odds of obesity were almost twice as high for women living in poor versus affluent neighborhoods (Sellstrom, 2009).

More recently, Mendez et al (2014) reviewed infant birth records from Allegheny County, Pennsylvania from 2003 - 2010 to determine

whether neighborhood socioeconomic disadvantage was related to GWG and pre-pregnancy BMI. Among the 55,608 women included in the analysis, 55.1% (n = 30,619) had excess GWG defined as greater than the pre-pregnancy BMI specific IOM recommendation ranges, and 41.0% (n=22,787) were overweight or obese at the start of pregnancy. Neighborhood socioeconomic status, operationalized using the Neighborhood Socioeconomic Disadvantage index (NSED), was not associated with excessive GWG or pre-pregnancy BMI among the study population (Mendez, 2014).

Currie et al (2010) sought to understand the association between proximity to a fast food outlet and maternal GWG using a large sample of approximately 3 million women in New Jersey, Texas and Michigan between 1989 and 2003. Women with a geocoded address within 0.5 miles from a fast food outlet had a 1.6% increase in the probability of a ≥ 20 kg weight gain in pregnancy (Currie, 2010). While Currie and colleagues characterized the built environment as a function of proximity to fast food outlets, Laraia et al (2007), Messer et al (2012) and Vinikoor-Imler et al (2011) evaluated the neighborhood environment by assessing physical incivilities (i.e. graffiti, residential vacancies) and social spaces (Laraia, 2007; Messer, 2012; Vinikoor, 2011). These variables were evaluated to determine the independent effect of each on GWG among women in North Carolina. Physical incivilities (i.e. litter, graffiti, poor housing conditions) were associated with excess GWG ($p = 0.010$) in the studies conducted by Messer et al (2012) and Vinikoor-Imler et al (2011) though no association was identified by Laraia et al (2007).

Methodological issues and gaps

The literature on the impact of neighborhood characteristics on the weight status of pregnant women suggest that additional research is needed to assess the relation of these factors with their health and that of their offspring. To study the effect of neighborhood environment on maternal weight status, the association between measures of the built, socioeconomic and social environments with maternal pre-pregnancy weight status and GWG need to be evaluated. In addition to the methodological problems with using pre-pregnancy BMI as a proxy of pre-pregnancy adiposity, and the appropriateness of GWG discussed above, constraints in this line of inquiry include residential stability/instability of women before and during pregnancy.

The neighborhood effects literature addresses aspects of the built (i.e. food environment), socioeconomic (i.e. percent below poverty) and social (i.e. crime) environments. These categories focus research on the contribution of community environment to obesity risk with the goal of identifying interventions to reduce obesity among reproductive age women and their children. The current body of literature, though small, varies in the neighborhood characteristics examined (i.e. food environment, neighborhood socioeconomic disadvantage index, territoriality, incivilities). As research on the impact of neighborhood effects on maternal pre-pregnancy BMI evolves, it will be important to ensure that all three aspects of environment are studied.

Research provides evidence of limited residential mobility of women during pregnancy (Miller, 2010); however, this author is unaware of literature which directly assesses residential stability among women ages 15 - 44 who are not pregnant. Understanding the residential mobility of women during the pre-gestation and gestation periods is

critical for correct assessment of neighborhood exposure. For example, most studies which explore neighborhood characteristics assume no migration of participants during the study period. This assumption is important for the internal validity of these studies as any residential move outside of the neighborhood challenges the relation between the study variables and actual exposure. In research focused on the impact of community characteristics on maternal pre-pregnancy BMI, residential stability before pregnancy is important while for research focused on the impact of neighborhoods on GWG, resident stability during pregnancy is important.

Measurement and determinants of child obesity

Children's weight status is challenging to estimate because of the variability in normal growth between birth and age 18. Childhood obesity is most commonly defined based on standardized curves produced by the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO). There are important distinctions between the WHO and CDC charts including differences by age group, growth indicators, and specific Z-score curves. The differences between the WHO and CDC models are largely the result of the study design and sample characteristics used to generate the curves (De Onis, 2007).

In the public health and clinical pediatrics literature, childhood overweight is most often defined as age- and sex-standardized body mass index (BMI; kg/m^2) between the 85th and 95th percentiles whereas childhood obesity is most often defined as age- and sex-standardized BMI \geq 95th percentile for children 2 years and older. Children's weight gain trajectory is also not consistently defined. It is most commonly calculated as the slope of age- and sex-standardized BMI percentiles over time, however, it has more recently been defined

as the number of weight-for-length percentiles crossed during 6-month intervals, between ages 1 to 6 months, 6 to 12 months, 12 to 18 months, and 18 to 24 months. (Danner, 2008; Taveras, 2011).

This section reviews the literature on maternal and neighborhood determinants of childhood overweight and weight gain trajectory. This section concludes with a discussion of the methodological issues and gaps in the literature.

Maternal characteristics and childhood obesity

Although links between maternal pre-pregnancy BMI and birth weight as well as between birth weight and childhood obesity have been reported, clarification of whether there is a direct relation between maternal pre-pregnancy BMI and childhood obesity is more complex. Factors which may confound, modify or mediate this association include birth weight, intrauterine growth restriction, maternal chronic disease (such as pre-gestational diabetes, pregnancy induced hypertension) and mode of delivery. Neighborhood characteristics and environmental exposures of the mother and child may also be important, although less often studied. Few studies have considered the full array of variables that may influence the association between pre-pregnancy weight and childhood obesity.

Research supports a direct association between maternal pre-pregnancy BMI and birth weight. Women who begin pregnancy obese are more likely to have macrosomic (birth weight \geq 4500 grams regardless of gestational age) and large-for-gestational age (LGA, birth weight \geq 90th percentile) births (Catalano, 2006; Ehrenberg, 2004; Ehrenberg, 2006). Two studies conducted in the 1960s were among the first to report this relation. Investigators showed a direct association between maternal pre-pregnancy weight and birth weight (Love, 1965). Shortly thereafter,

Eastman et al assessed the independent impact of maternal pre-pregnancy weight and height as predictors of birth weight (Eastman, 1968). While both were positively associated with birth weight in univariate analysis, height was no longer significantly associated with birth weight after including pre-pregnancy weight in the model (Eastman, 1968).

Research on this association has expanded since the 1960's. In a recent meta-analysis, Yu et al assessed the association between maternal pre-pregnancy BMI and birth weight, macrosomia and LGA (Yu, 2013). In a review of 37 articles adjusting for maternal demographic (age), health (gestational diabetes) and social (marital status) characteristics, investigators observed that women with a BMI ≥ 25 kg/m² had a 53% greater odds of high birth weight (≥ 4000 grams), 67% greater odds of macrosomia and 53% greater odds of LGA compared with their normal weight counterparts (< 25 kg/m²). Furthermore, obese women (BMI ≥ 30 kg/m²) had twice the odds of having high birth weight or LGA births and over three-fold increase in odds of delivering a macrosomic neonate. Yu and colleagues deemed all 37 of these studies to be either high or medium quality based on variable measurement and study design.

For all studies included in the meta-analysis, maternal pre-pregnancy BMI was analyzed as an ordinal variable based on accepted schema as recommended by Abrams and Parker (2011), the WHO, the Institute of Medicine (IOM) and the BMI classification for Chinese adults proposed by the Working Group on Obesity in China and the Asia-Pacific standard (APS). In addition, the articles in this work classified birth weight as commonly reported in the literature including LGA, high birth weight (HBW) ≥ 4000 g and macrosomia. Studies that defined offspring overweight/obesity categories according to BMI were also included (i.e. CDC and WHO standard reference curves). The

findings support the conclusion that normal weight women are less likely to deliver high birth weight, macrosomic or LGA infants when compared to overweight and obese women, and that risk increases with increasing pre-pregnancy BMI. The results also suggest a direct association between maternal pre-pregnancy BMI and odds of delivering high birth weight, macrosomic and LGA children (Yu, 2013).

Many studies have investigated the association between birth weight and obesity in later childhood and adolescence. Though these cohort studies assess BMI in later childhood, practical limitations of prospective follow-up make it challenging to evaluate weight trajectories and the long-term health and social implications for children born high birth weight, macrosomic or LGA. Of the close to 40 primary sources that reported an association between birth weight and childhood obesity included in the same systematic review by Yu et al, the most frequent relation noted was a direct positive association between birth weight and BMI in late childhood. Most studies of children show that for each kilogram increase in birth weight, BMI for children age 2 and over increases by 0.5 to 0.7 kg/m² (Yu, 2013). While some small studies found a null association between birth weight and childhood BMI, no study noted an inverse relation. Of the 20 primary research studies evaluated in a systematic review compiled by Parsons et al, 19 reported a positive association between birth weight and BMI in later childhood. While some work cited by Yu et al failed to adjust for gestational age at birth, similar findings were reported regardless of whether the researchers did or did not adjust for gestational age (Parsons, 1999).

The direct link between maternal pre-pregnancy BMI and obesity in children older than 2 years has been evaluated in many studies. Few studies, however, adequately adjust for the breadth of covariates which

may mediate or confound the association between maternal pre-pregnancy BMI and childhood overweight/obesity and weight gain trajectory.

Studies that did and did not adjust for these covariates are reviewed below.

In 1998, Rooney et al explored predictors of obesity in childhood, adolescence and adulthood, reporting on approximately 800 children who were delivered in a large Midwest health system. Children of women with a pre-pregnancy BMI ≥ 30 kg/m² had a 4.3 times greater odds of being obese at age 4 - 5 year than those of normal or overweight mothers after adjusting for maternal chronic disease, delivery type, infant birthweight, weight gain in the first 4 months of life, gestational weight gain and maternal smoking history (Rooney, 2011).

The Quebec Longitudinal Study of Child Development investigated early determinants of overweight at 4.5 years in a cohort of approximately 2100 children born in 1998. The authors found that children born to overweight and obese women had two-fold greater odds of overweight and three-fold greater odds of obesity at 4.5 years old after adjusting for birth weight and estimated gestational age at the time of delivery. Maternal pre-pregnancy BMI was not measured but rather maternal BMI was assessed 18 months postpartum; these results must be cautiously interpreted as they do not account for postpartum weight gain or variables associated with weight gain in the postpartum period (depression, short interpregnancy interval) (Dubois, 2006) nor do they consider the roll of social environment in maternal and child BMI status.

Hawkins et al examined risk factors for early childhood overweight/obesity in a sample of 12,576 singleton children ages 0-5 years in the UK Millennium Cohort Study. They reported that higher maternal pre-pregnancy BMI was associated with an increased odds of

childhood overweight or obesity at 3 years old, after adjusting for birth weight (Hawkins, 2009). Additional research by Reilly and colleagues (2005) reported that after adjusting for both birth weight and birth weight z-score, maternal pre-pregnancy obesity was associated with an over three-fold increased odds of childhood obesity at age 7 in a sample of 13,971 maternal-child pairs enrolled in the Avon longitudinal study of parents and children. Over 14,541 pregnant women with an expected date of delivery between April 1, 1991 and December 31, 1992 in the United Kingdom were followed in this retrospective cohort study. The purpose of the study was to evaluate determinants of development, health and disease during childhood. Reilly et al specifically aimed to identify risk factors for obesity in children up to 5 years of age (Reilly, 2005).

Ehrenthal et al identified a similar association between maternal pre-pregnancy BMI and offspring BMI z-score at age 4 in the Delaware Mother and Baby Cohort, a mother and child linked database of women who delivered at Christiana Care Health System (CCHS) between January 1, 2004 and December 31, 2007 and who accessed pediatric care for their child through the Nemours Children's Health System (NCHS) at least once between January 1, 2004 and May 31, 2011. In this study, maternal pre-pregnancy BMI was significantly and positively related to child BMI z-score at age 4 after adjusting for pre-gestational and gestational diabetes, gestational hypertension/preeclampsia, tobacco use, gestational weight gain adjusted for gestational age at birth, infant sex and maternal demographic characteristics (Ehrenthal, 2013). No adjustment for birth weight was made in this study.

Heerman et al performed a retrospective study of almost 500 mother-child dyads born between January 2007 and May 2012 to evaluate the joint effect of maternal pre-pregnancy obesity and gestational

weight gain on infant growth trajectory (Heerman, 2014). The researchers found an interaction between gestational weight gain and pre-pregnancy BMI with infant growth trajectory. Infants of women with a pre-pregnancy BMI $> 40 \text{ kg/m}^2$ as well as excess gestational weight gain had a 13.6% greater increase in 3-month weight/length percentile than infants of women with excess gestational weight gain and a pre-pregnancy BMI of 25 kg/m^2 . This weight/length differential persisted at 12 months.

Yu et al identified four studies in the literature which supported a direct relation between pre-pregnancy BMI and overweight and obesity in offspring (Yu, 2013). The pooled odds of childhood overweight/obesity for overweight women was 1.95 and 3.06 for obese women (Gewa, 2010; Khashan, 2009; Laitinen, 2012; Padez, 2005). Moreover, in a systematic review performed by Baidal et al, 38 articles were cited which evaluated the impact of maternal pre-pregnancy BMI on childhood obesity in the first 1000 days of life. Higher maternal pre-pregnancy BMI had a consistent relation with overweight later in childhood in 34 of the 38 investigations (Baidal, 2016). Although these studies adjusted for important variables including birth weight, they did not simultaneously assess the full array of maternal factors associated with childhood obesity.

Neighborhood environments

This section reviews the literature evaluating the association of neighborhood characteristics with child overweight/obesity. The relation between the built environment, the social environment and the socioeconomic environment and childhood overweight/obesity are discussed separately given the breath of literature on each neighborhood characteristic. Gaps in knowledge as well as the

methodological limitations of this body of research are reviewed at the end of this section.

Built, physical and food environment

The relation between built, physical and food environment and childhood overweight/obesity prevalence is the most comprehensively studied of all neighborhood characteristics in relation to childhood weight status. Of the 60 articles that assessed the relation between the built environment and child overweight/obesity, 37 studies measured neighborhood food environment (An, 2012; Bader, 2013; Burdette, 2004; Carroll, 2013; Casey, 2012; Cetateanu, 2014; Chaparro, 2014; Currie, 2010; Davis, 2009; Epstein, 2012; Fiechtner, 2013; Fiechtner, 2015; Fraser, 2010; Fraser, 2012; Galvez, 2009; Gose, 2013; Grafova, 2008; Griffiths, 2014; Harris, 2011; Harrison, 2012; Jennings, 2011; Jerrett, 2010; Koleilat, 2012; Laska, 2010; Lee, 2012; Leung, 2011; Liu, 2007; Mellor, 2011; Navalpotro, 2012; Oreskovic, 2009; Powell, 2007; Powell, 2012; Salois, 2012; Seliske, 2009; Shier, 2012; Sturm, 2005; Wasserman, 2014). The measurement of food environment included variables such as the straight-line distance between the child's home and the nearest healthy food outlet (supermarkets, farmer's markets) and the number of fast food venues within the child's census tract. Five of the 37 studies showed no association between the food environment and child overweight/obesity (Gose, 2013; Griffiths, 2014; Harris, 2011; Lee, 2012; Navalpotro, 2012). The 29 studies in which a significant association was recognized reported considerable variability in the impact of healthy and unhealthy food environments on child obesity.

Most studies investigating the impact of unhealthy food environment are focused on older age children and find these food environments are associated with increase BMI in children. For example,

in the cross-sectional study by Harrison and colleagues (2011), the relation between access to convenience stores and fat mass index (FMI) was investigated in a cohort of approximately 2000, 9-10 year-old children in Norfolk, UK. Among girls in this sample, increased access to unhealthy food outlets was associated with higher FMI; however, this association was not observed among boys. Davis et al (2009) used geocoded data on ~500,000 children who participated in the California Healthy Kids Survey to estimate the association between childhood obesity and proximity of fast-food restaurants to schools. Children with fast-food restaurants within 1 mile of school had a higher odds of overweight (OR = 1.06; 95% CI: 1.02, 1.10) and obesity (OR = 1.07; 95% CI: 1.02, 1.12) although the relationship was not strong (Davis, 2009).

Studies that characterized healthy food environment found less consistent results (Harrison, 2011). Feichtner et al (2015) examined the extent to which proximity to six types of food establishments was associated with BMI z-score in a sample of approximately 50,000 children 4-18 years old in Eastern Massachusetts. In this analysis, living near large and small supermarkets was associated with lower BMI (Feitchner, 2015). In a similar study of 7,334 children aged 3-18 years in Marion County, Indiana, Liu and colleagues (2007) found that increased distance between the children's residence and the nearest large brand name supermarket was associated with increased risk of overweight, but only for children living in rural areas (Liu, 2007). In contrast, Epstein et al (2012) evaluated the relation between the food environment and CDC standardized BMI changes in a sample of 191, 8-12 year olds who participated in one of four randomized control trials on pediatric weight management. At 2-year follow up, fewer supermarkets were associated with greater BMI reduction; thus, decreased access to

healthy food environment was associated with increased weight loss, the opposite of the hypothesized effect (Epstein, 2012).

Seventeen studies measured the impact of neighborhood walkability and street connectivity on child weight status (Crawford, 2008; Crawford, 2010; Duncan, 2012; Duncan, 2014; Epstein, 2012; Fleisch, 2015; Gose, 2013; Grafova, 2008; Harrison, 2011; Jerrett, 2010; Klingerman, 2007; Lovasi, 2011; Nelson, 2006; Oreskovic, 2009; Slater, 2010; Timperio, 2010; Wolch, 2011). Like food environment, there are mixed findings regarding the association between walkability and child overweight/obesity risk. Lovasi et al (2011) examined the association between neighborhood walkability and BMI among 428 preschool children from low-income families in New York City. Subway stop density, a proxy for ease of urban walkability, was directly associated with decreased adiposity ($p = 0.001$) (Lovasi, 2011). In contrast, Duncan et al (2012) found that density of bus stops was not associated with BMI z-scores in a sample of over 1000 high-school children in Boston, MA (Duncan, 2012).

In 2007, a cross-sectional study by Kingerman et al of 98 white or Mexican-American adolescents evaluated the association between a neighborhood walkability index and BMI. Neighborhood walkability, although significantly associated with the physical activity of study participants, was not associated with BMI (Klingerman, 2007). Similarly, in a study conducted by Crawford et al (2010), road connectivity was not associated with BMI change over 5 years follow up in a sample of 301 children ages 10-12 in Melbourne, Australia (Crawford, 2010). Finally, Gose et al (2013) studied walkability in 485, 5 - 6 year old children from Kiel, Germany. In this sample, children residing in the least walkable neighborhood had lower BMI ($OR = 0.45$; 95% CI: 0.19 - 0.71] (Gose, 2013).

Nine studies evaluated whether population density and urbanization were associated with child obesity (Bell, 2008; Casey, 2012; Duncan, 2014; Grafova, 2008; Jerrett, 2010; Lovasi, 2011; Schwartz, 2011; Slater, 2010; Wolch, 2011). In one study conducted by Bell et al (2008), a sample of over 3,800 3 - 16 year-old children and youth from Marion, IN was evaluated to discern the association between residential density and a 2-year change in BMI (Bell, 2008). Higher residential density was not associated with change in BMI. However, in a similar study by Duncan and colleagues in (2014), the result of multivariable cross-sectional models indicated that children ages 4 - 19 who lived in census tracts with lower residential density had higher BMI (Duncan, 2014). Schwartz et al (2011) reported contrasting results in 48,000 5 - 18 year-old children residing in Pennsylvania. Children inhabiting census tracts with higher population density had lower BMI values than those in less dense tracts (Schwartz, 2011).

Twenty-five studies were identified in which the association between physical activity (PA) environment and child obesity was investigated (Albaladejo, 2014; Bell, 2008; Burdette, 2004; Casey, 2012; Crawford, 2008; Crawford, 2010; Duncan, 2012; Epstein, 2012; Gordon, 2006; Gose, 2013; Jerrett, 2010; Kipke, 2007; Liu, 2007; Lovasi, 2011; Navalpotro, 2012; Nelson, 2006; Potwarka, 2008; Saelens, 2012; Salois, 2012; Schwartz, 2010; Slater, 2010; Taylor, 2014; Timperio, 2010; Wasserman, 2014; Wolch, 2011). PA environment was most commonly measured by the distance between child residence and the nearest parks/recreation, the distribution of green space in the census-tract or the number of community physical fitness centers. Although 2 studies found no significant association, the majority of studies indicate that closer proximity to parks/recreation, more green space and higher number of physical fitness centers are associated with

decreased obesity. For example, the relation between accessibility to physical fitness facilities and BMI was evaluated in a cross-sectional study of over 3,200 middle-school students in 2001. Students were categorized by family socioeconomic status. (blue-collar-workers' children/non-blue-collar-workers' children). Children of blue-collar-workers had a higher likelihood of being overweight when spatial accessibility to urban PA facilities was low, although a similar relation was not observed in children of non-blue-collar-workers (Casey, 2012). This finding indicates that PA environment may interact with familial socioeconomic status.

In a nationally representative sample of over 33,000 8th and 10th graders in 2001 - 2003, the relation between neighborhood physical activity friendliness and BMI was evaluated. The authors conducted a sensitivity analysis to determine which aspects of the PA environment contributed independently to BMI. Of the PA friendliness metrics evaluated, only the existence of bike paths was significantly associated with decreased obesity (Slater, 2010). Similar findings were published by Taylor et al (2014) in which greater accessibility to PA facilities was negatively correlated with both BMI and prevalence of weight-height ratio > 0.5 in a sample of 911, 5 - 12 year old children residing in 13 neighborhoods in the southeastern US (Taylor, 2014). When PA environment was measured as park space within a 500 m buffer from child residence in the Southern California Children's Health Study, a significant inverse association was reported with attained BMI at 18 years of age (Wolch, 2011).

Community built environment is a broad category which includes the distribution of food outlets, the accessibility of green space and the physical layout of a neighborhood. This research focuses on one component of the built environment, proximity to healthy food outlets.

As outlined above, most research on the association between food environment and childhood obesity was conducted in middle- and high-school aged children given their ability to purchase food independent of parent influence. Scant research explicitly evaluates the role of food environment on BMI in early childhood as parental decision-making likely has a greater impact on food consumption during this time. As a result, the role of food environment in early childhood is best conceptualized as a maternal-child (or parental-child) exposure. It is commonly evaluated in research which considers the impact of maternal weight status along with food environment on early childhood BMI and BMI trajectory. This author is unaware of any research which has evaluated the effect of both maternal characteristics and of food environment on early childhood BMI in the same model.

Social environment

The social environment refers to the relationships, groups and social processes that exist between individuals and groups in a neighborhood. Supportive environments include neighborhoods where residents can form healthy interpersonal relationships and social support networks characterized by cohesion, trust and social capital. Cohesive neighborhoods enable citizens to form relationships and have been shown to support healthy decision-making among children in the community (Carroll, 2013). Though aspects of neighborhood social environment have been associated with adult obesity, this author is unaware of research evaluating the impact of constructs such as social cohesion or community trust on child weight status. While these associations have not directly been assessed, proxy measures of the lack of neighborhood social cohesion, including neighborhood crime, have been evaluated as predictors of childhood weight status. Six

studies directly evaluated the independent effect of neighborhood crime on child obesity (Carroll, 2013; Grafova, 2008; Lovasi, 2011; Miranda, 2012; Nelson, 2006; Salois, 2012). Of these six studies, four found a statistically significant direct association between crime rates and child obesity whereas two reported no association.

Carroll-Scott and colleagues (2013) found that children residing in census tracts with higher levels of poverty and crime had higher BMI in a sample of 1048 fifth and sixth graders in New Haven, Connecticut (Carroll, 2013). Miranda et al (2012) found a similar association among children living in neighborhoods with medium and high levels of violent crime (Miranda, 2012). The county-level criminal activity rate was also found to be directly associated with obesity among low-income preschool children included in the Pediatric Nutrition Surveillance System (Salois, 2012).

Using a different approach, Nelson and colleagues evaluated the impact of serious crimes (i.e. arrests) per 100,000 persons on childhood overweight/obesity in the National Longitudinal Study of Adolescent Health. High crime tracts were found to characterize 'mixed race/ethnicity urban' and 'low-SES inner city' neighborhoods. Each neighborhood patterns had higher prevalence of obesity among residing adolescents (Nelson, 2006). Like research on food environment, scant research on the association between social environment and BMI is explicitly focused on young children. Additional research is critical to determine the association between characteristics of neighborhood social environment and BMI in young children as these associations are likely different than factors which impart risk in later childhood.

Socioeconomic environment

The socioeconomic environment of a neighborhood refers to the combined socioeconomic composition of a community as well as the impact of absolute neighborhood wealth and wealth distribution on community members (Carroll, 2013). Research supports the finding that children who live in low socioeconomic status (SES) neighborhoods have worse health status (O'Campo, 1997). A total of 31 articles evaluated the impact of socioeconomic environment on overweight/obesity in children.

Socioeconomic environment is typically measured as either neighborhood deprivation or disadvantage using a composite index, though census measures of neighborhood income are also used (Albaladejo, 2014; Booth, 1999; Carroll, 2013; Cetateanu, 2014; Conrad, 2012; Edwards, 2010; Gordon, 2006; Grafova, 2008; Grow, 2010; Jansen, 1997; Janssen, 2004; Kimbro, 2013; Kinra, 2000; Li, 2014; Liu, 2007; Lovasi, 2011; Nau, 2015; Navalpotro, 2012; Nelson, 2006; Oliver, 2005; Oreskovic, 2009; Rossen, 2014; Rossen, 2014; Schwartz, 2011; Sherburne, 2009; Shih, 2013; Wasserman, 2014; Wolch, 2011; Zhang, 2007). Composite measures of socioeconomic deprivation or disadvantage often incorporate attributes of the social environment (described above) as well as measures of income status and residential wealth. The literature on the impact of socioeconomic deprivation and disadvantage and child overweight/obesity is much more consistent than that of neighborhood built and social environments in that almost all studies found an inverse association between socioeconomic deprivation and child overweight/obesity.

Most research on neighborhood socioeconomic deprivation and child obesity has been conducted outside the United States. Conrad and colleagues evaluated the association between neighborhood deprivation and rates of childhood overweight/obesity in a nationally representative sample of England. The measure of neighborhood

socioeconomic environment, the community index of multiple deprivation, was strongly associated with obesity rates in school age children ($r = 0.625$, $p < 0.001$). A similar correlation was not identified for overweight children in the sample (Conrad, 2012). Also in the UK, children residing in deprived neighborhoods (i.e. 'blue collar communities,' 'constrained by circumstance') had significantly higher obesity levels.

While less research has evaluated the impact of neighborhood socioeconomic deprivation and child overweight/obesity in the United States, the existing research supports a similar association. Grow et al (2010) concluded that prevalence of childhood obesity was higher among children residing in census-tracts with lower mean household income compared to those with higher mean household income, with lower percentages of home ownership as compared to census-tracts with higher percentage of rental units, and with each 10% increase in less educated women within the tract (Grow, 2010). Shih et al (2012) evaluated the impact of economic hardship on obesity in children in Los Angeles County, California (Shih, 2013). In this study, higher community-level economic hardship was associated with higher child obesity prevalence ($p < 0.001$) and communities with the highest level of economic hardship had more than double the obesity prevalence as communities with the lowest level of economic hardship.

Methodological issues and gaps

The association between maternal and child obesity is likely the result of a combination of intrauterine factors and shared maternal-child susceptibilities and neighborhood exposures, including aspects of the built, social, and socioeconomic environment. Because of the concordance of behavior between mother and child (food preferences,

eating behavior and obesity incidence), the variability in early childhood weight status that can be explained by maternal intrauterine factors alone is likely small when compared to other maternal, child and environmental factors. Although it is difficult to identify the independent effect of each component, understanding the association between maternal and neighborhood characteristics may clarify how much of early childhood weight status results from in utero exposures versus environmental factors common to the mothers and their infants throughout pregnancy and into early childhood.

Though study of the impact of neighborhood characteristics on child overweight/obesity has increased over the past decade, methodological concerns as well as literature gaps remain. First, by its very nature, existing research is observational in nature and thereby unable to assess a causal association between neighborhood characteristics and children's overweight/obesity and weight gain trajectory. Second, most of this work is conducted within geopolitical areas such as cities or counties. These jurisdictions, though often both racially and socioeconomically diverse, may be homogeneous in population density and green-space and thereby limit the range of built environmental exposures that can be evaluated. Third, although family characteristics (i.e. maternal education, family income level) are often considered as covariates in models relating neighborhood characteristics to child overweight/obesity, no research to date has evaluated the independent effects of maternal pre-pregnancy BMI and neighborhood characteristics on child BMI.

The effects of community characteristics on health are believed to be cumulative (Kawachi, 2010). However, the level of exposure is rarely evaluated in studies relating neighborhood characteristics to child overweight/obesity; therefore, the hypothesis that greater levels

of neighborhood exposures result in higher levels of obesity (biologic gradient) has not been evaluated. To assess whether a biologic gradient or a dose-response relationship exists between neighborhood characteristics and child weight status, both the duration of exposure (dose) as well as the trajectory of weight gain (response) must be measured.

Although the ideal solution to this methodological conundrum would be empirical measurement of these variables in prospective cohort studies, given the large resource burden of this type of research, developing innovative methods to adjust for these factors within the confines of established retrospective cohorts may be useful. Methods to capture duration of exposure include repeated surveillance of research participants as well as analysis of inter-neighborhood migration within a population. Retrospective analysis of child anthropometry using health record data provides longitudinal information on pediatric weight trajectories without the expense of prospective follow-up. These methodological approaches help researchers assess the temporality between neighborhood exposures and rate of weight gain, and thus, improve understanding of the association between the two variables.

The relation between neighborhood characteristics and child obesity is often studied within uniform geopolitical areas such as cities or counties. Although some jurisdictions represent both socially and geographically diverse communities, many studies include only a narrow range of census-tract levels. Given that most research considers census-tracts as proxies for neighborhoods, high variability in the built, social and socioeconomic environments within census-tracts is critical to evaluate the impact of neighborhoods on population outcomes.

As research on the determinants of child obesity expands, including risk factors at multiple levels of the ecological framework will become increasingly important. Though multiple studies have evaluated the impact of neighborhood and family characteristics on child weight status, no research to date has simultaneously explored the impact of maternal pre-pregnancy BMI and neighborhood characteristics on child overweight/obesity. Considering both maternal and neighborhood influences in the same model will allow researchers to clarify whether an independent association exists between neighborhood characteristics, maternal weight status and child overweight/obesity.

Table 2-1: World Health Organization (WHO) classification of weight status

| Classification | BMI (kg/m ²) |
|------------------------|--------------------------|
| Low weight | < 18.5 |
| Normal weight | 18.5 – 24.9 |
| Overweight – pre-obese | 25.0 – 29.9 |
| Obese class | |
| I | 30.0 – 34.9 |
| II | 35.0 – 39.9 |
| III | > 40.0 |

Table 2-2: Institute of Medicine (IOM) guidelines for gestational weight gain

| Pre-pregnancy BMI (kg/m ²) | Weight gain (kg) | Weight gain (lbs) |
|---|---------------------|----------------------|
| < 18.5 | 12.7 – 18.1 | 28.0 – 40.0 |
| 18.5 – 24.9 | 11.3 – 15.9 | 25.0 – 35.0 |
| 25.0 – 29.9 | 6.8 – 11.3 | 15.0 – 35.0 |
| ≥ 30.0 | 5.0 – 9.1 | 11.0 – 20.0 |

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3. Research Design and Methods

The two aims of this research were: (1) to investigate the independent associations of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on weight status of children at age 5, and (2) to evaluate the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on BMI trajectories of children from 2 to 8 years old in the Delaware Mother and Baby Cohort. To address these aims, the association between census-tract socioeconomic deprivation, neighborhood food environment, and maternal pre-pregnancy obesity was also evaluated.

This chapter includes a description of the Delaware Mother and Baby Cohort (DMBC), the main source of maternal-child data used in this research. In addition, the chapter details the neighborhood data merged to the DMBC. It also describes the aim-specific study samples, variables, analytic methods and human subject protection.

The Delaware Mother Baby Cohort

The DMBC is a mother and child linked database of women who delivered at Christiana Care Health System (CCHS) in Newark, Delaware between January 1, 2004 and December 31, 2007, and who accessed pediatric care for their child through the Nemours Children's Health System (NCHS) at least once between January 1, 2004 and May 31, 2011. The DMBC was derived from a merge of data from the CCHS obstetric medical records of singleton births and the electronic medical records of the subset of children cared for in the NCHS general pediatrics practices during the study period. All maternal medical and obstetric data in the DMBC were abstracted from CCHS delivery medical records.

Figure 3-1 describes the timeline for the mother and child samples for which obstetric and pediatric medical records were selected and merged.

CCHS is a regional private not-for-profit health system located in Newark, Delaware. As the biggest hospital in Delaware and one of the largest in the mid-Atlantic, CCHS provides care to much of the State and surrounding region (Christiana Care Health System, 2015). During the study period, CCHS was a National Community Center for Excellence in Women's Health,² the only hospital in Delaware with a Level 3 neonatal ICU and the largest birthing facility in the State with over 7,000 deliveries annually (Christiana Care Health System, 2015). The facility handles over 85% of obstetrical care in Delaware and because of its location, cares for a geographically, racially and socioeconomically diverse patient population (Christiana Care Health System, 2015).

Table 3-1 compares demographic and birth statistics at the hospital, state and national level (Ehrenthal D., personal communication, 2011; Nemours Children's Health System, 2016; Hamilton, 2015). Socio-demographic characteristics of CCHS obstetric patients reflect the makeup of Delaware and the United States; however, a larger percentage of CCHS patients are publicly insured. A comparison of the racial/ethnic distribution between populations is notable for a lower percentage of Hispanic and higher percentage of black women who accessed obstetric care at CCHS and in Delaware than in the United States. However, Hispanic ethnicity is considered a racial category in hospital and state data compared to an ethnicity in national estimates.

² The **National Centers of Excellence in Women's Health** (CoE) were established in 1996 by the US Department of Health and Human Services' Office on Women's Health. The Centers are located in academic medical centers where they bring together the work of their schools and departments addressing women's health. The grant program was last funded in fiscal year 2016 and ended 8/31/16.

The difference in categorization makes it challenging to compare this variable across populations.

NCHS is based in Jacksonville, Florida and manages the Nemours/Alfred I. DuPont Hospital for Children (AI Dupont) along with five additional outpatient pediatric clinics in Wilmington, Delaware. Nemours also operates outpatient pediatric clinics in six Delaware towns including: Bear, Dover, Middleton, Milford, Newark and Seaford (Nemours Children's Health System, 2018). Pediatric well child care is available at each NCHS outpatient practice as well as on-site at AI Dupont hospital. Because of the geographic distribution of NCHS pediatric clinics, the system provides primary care for children throughout the state. Like CCHS, the NCHS general pediatrics practice serves a racially, socioeconomically and geographically diverse patient population which mimics the demographic characteristics of the US and Delaware (Nemours Children's Health System, 2016).

Child anthropometric data were collected from the NCHS electronic medical record according to the well-child schedule recommended by the American Academy of Pediatrics (AAP). These data were abstracted at the following ages: 2 weeks, 1 month, 2 months, 4 months, 6 months, 9 months, 12 month, 15 months, 18 months, 2 years, 3 years, 4 years, 5 years, 6 years, 7 years and 8 years. Individual visit data were considered complete if visit date, weight (pounds) and height (height) were recorded.

To categorize well-child visits into AAP scheduled encounters, child age at each appointment was calculated using visit date and date of birth. The age distribution surrounding each AAP recommended visit was reviewed and a window corresponding to each clinical encounter was created (i.e. age window corresponding to 36-month visit was 33 - 45 months old at time of the NCHS encounter). Each child encounter was

assigned to an AAP recommended scheduled visit based on the defined age window. In the event greater than one visit occurred during any given time interval, visit type (i.e. 'well-child visit', 'specialty provider visit') was reviewed and the encounter corresponding to the well-child exam was included. In cases when only specialty or acute-care appointments corresponded to a given AAP scheduled visit, the encounter was considered missing. In situations when multiple well-child exams occurred in the same window, the visit closest to the precise age of the AAP scheduled visit was used. The distribution and anthropometric characteristics of DMBC children with visits at each AAP recommended visit is included in **Table 3-2**.

The maternal and child medical records for all DMBC dyads were merged in June 2011. From January 1, 2004 to May 31, 2011, over 26,000 singleton live births occurred at CCHS. Approximately 14,000 children with birth dates during this time frame had at least one well-child visit with a NCHS pediatric provider between January 1, 2004 and May 31, 2011 (Christianity Care Health System, 2015). The births in the CCHS dataset were matched to children in the NCHS dataset using five variables common to both sources: mother's first and last name; child's first name, last name and date of birth. Data were linked using Fine-Grained Record Integration and Linkage (FRIL) software using weighted matching parameters to create a matched confidence level (*Fine Grained Record Linkage Software*. Release 1.1.4. Emory University. Atlanta, GA).

Data were automatically accepted as a match at a confidence parameter of 80%, and data with a confidence level of less than 50% were automatically discarded as non-matching observations. Data were manually reviewed when the FRIL confidence parameter fell between 50.0 - 79.9%. A total of 4,450 mother-child matches were automatically linked based on the FRIL weighted algorithm and 402 were manually

reviewed based on FRIL guidelines for a total of 4,852 mother-child pairs. The most common reasons for manual matching included hyphenated name, change of mother or child's last name since birth, or mother or child's name was spelled incorrectly in either the CCHS or NCHS record.

In November 2012, NCHS data was re-queried to identify DMBC children who had additional well-child encounters between June 2, 2011 and November 8, 2012. An additional 1,926 pediatric anthropometric records were merged with the DMBC after this second data abstraction. A total of 20,391 encounters for the 4,852 DMBC mother-child pairs (mean = 4.2 visits/patient) were included in the final data.

Additional data linkages

In addition to the DMBC, three data sources informed this research: (1) Delaware birth certificates; (2) the 2010 US Census (US Decennial Census 2010; American Community Survey Data 2010 5-year estimates) and; (3) the Delaware Healthy Toolkit Food Resource Database (FRD). All three supplemental data sources were merged with the DMBC using variables common to each. The specific criteria linking the DMBC data with other sources are described below.

Delaware vital statistics: birth certificates

Birth certificates from 2004 to 2007 for each DMBC maternal-child pairs was obtained from the Delaware Department of Health and Social Services (DHSS) Division of Public Health, Office of Vital Statistics. Maternal socio-demographic and maternal and newborn health information from the birth certificate was merged with DMBC data using mother's last name and date of birth and the child's date of birth. Of the 4,852 maternal-child pairs included in the DMBC, 4,844 (99.8%) were matched to birth certificate data.

United States Census

United States census data provided information about neighborhood-level characteristics compiled for census tracts. United States census tracts are governmental boundaries comprised of approximately 4,000 residents. These areas are defined based on local input and are intended to represent neighborhoods. There were 196 census tracts in Delaware in 2010 with a mean population of approximately 4,196 residents per tract (Delaware Health Statistics Center, 2016).

Dyadic data were merged with census tract data from the 2010 US Census to characterize neighborhood socioeconomic position using a census-tract deprivation index to evaluate the effect of deprivation on maternal pre-pregnancy BMI and childhood weight status. The maternal address at the time of delivery documented in the obstetric medical record was geocoded using ArcGIS software (*ArcGIS Release 10.1*, Redlands, CA.) and linked to the census tract unique identification geocode. When no current maternal address was listed on the CCHS record, the child's address documented at the first NCHS encounter was used as an alternative ($n = 12$). Census data were subsequently merged to core data based on this tract-level identifier. Of the 4,844 DMBC mother-child pairs matched to birth certificates, 45 were without valid addresses and could be matched to Delaware census-tract data ($n = 4779$ were matched, 98.5%).

Delaware Healthy Toolkit

Delaware food environment data were collected by the University of Delaware Institute for Public Administration, School of Public Policy for the *Healthy Delaware Toolkit*. This web-based resource allows local government, community leaders and citizens to access information

on opportunities for physical activity and access to healthy foods in their municipalities. Locations of food outlets were compiled in the Food Resource Database (FRD) from established databases of the Delaware Division of Public Health, the Delaware Economic Development Office, the Delaware Department of Agriculture and the Delaware Department of Natural Resources and Environmental Control. In addition, data were reviewed, and locations were added based on discussions with community leaders to identify retailers absent from preexisting data sets. The FRD was developed to represent the Delaware food environment in 2009 and 2010; each outlet was contacted by the author to confirm operation between January 1, 2004 and December 31, 2007, the DMBC delivery eligible timeframe. Of the 190 retailers included in the FRD, 182 were active businesses for at least 24 months during the study period.

The correct address for all 182 active food outlets during the study period was confirmed with a representative from each location and subsequently geocoded to a latitude and longitude coordinate using ArcGIS software. The straight-line distance between each maternal address and each food outlet was calculated. The venue with the shortest straight-line distance to each maternal-child address was identified and used for analysis. Of note, this measure does not represent true travel time between the dyad's residence and the closest food outlet.

Study samples

The study samples for each specific aim were drawn from the final merged DMBC database. **Figure 3-2** is a flow diagram of study sample inclusions and exclusions. It is well established that children with underlying disease often have abnormal growth (De Onis, 2007). Of the original sample, 214 children with a documented birth defect or other

chronic disease known to impact growth (i.e. cancer, chronic gastrointestinal disease, metabolic disorder) were excluded from the study sample. An additional 27 maternal-child pairs were excluded due to missing or erroneously recorded maternal pre-pregnancy BMI. A total of 4,558 maternal-child pairs were eligible for inclusion in subsequent analyses.

Specific Aim 1 investigated the independent association of maternal pre-pregnancy BMI, census-tract socioeconomic deprivation and neighborhood food environment with child weight status at age 5. The sample for this aim was limited to maternal-child pairs with a documented child height and weight obtained during an NCHS encounter corresponding to the 5-year old well-child visit; 1,457 maternal-child pairs with no 5-year old visit were excluded. All 3,101 (63.9% of the DMBC) remaining maternal-child pairs had complete covariate data and represent the analytic sample for Specific Aim 1.

Specific Aim 2 investigated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on BMI trajectories of DMBC children from ages 2 to 8 years. The sample for this aim was limited to maternal-child pairs with a documented height and weight for at least 2 NCHS pediatric encounters from 2 to 8 years to calculate a child's BMI rate of change during this timeframe; 664 maternal-child pairs were excluded for which the child had only one visit. An additional 32 maternal-child pairs were excluded for trajectories that fell above or below 5 standard deviations from the mean rate of BMI change. All remaining 3,862 maternal-child pairs had complete covariate data with exception of 3 children for whom birth weight was not recorded. Missing birth weights were imputed for these children based on gestational age

and child sex. A total of 3,862 (79.6% of the DMBC) maternal-child pairs were included in the analysis for Specific Aim 2.

Variables

Table 3-3 summarizes the study variables. They included the two dependent variables, child BMI at age 5, child BMI trajectory from 2 to 8 years old, maternal socio-demographic, pre-pregnancy health and pregnancy health characteristics as well as neighborhood factors believed to influence child obesity and weight gain trajectory. In addition, cohort characteristics (birth year and follow-up time) were included.

Dependent variables

BMI percentile is often used to assess risk for subsequent diseases in later childhood, adolescence and adulthood. Change in BMI has been shown to be a better predictor of change in adiposity than change in BMI percentile or change in BMI z-score. Childhood adiposity had been shown to be directly associated with chronic diseases of adulthood (Cole, 2005; Juonala, 2011). In addition, change in BMI in early-to-middle childhood has been shown to correlate with risk for adult chronic disease (Cole, 2005).

Specific Aim 1 evaluated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with child weight status at age 5. The sex-specific BMI percentile for 5-year old children was used for this analysis. Child BMI at 5-years was calculated from anthropometric data included in the pediatric electronic medical record; it was defined as the mass (kilogram) divided by the square of the height (meter) using each child's anthropometric measurement assessed at the 5-year clinical

encounter (visit window: 57 – 66 months). Using the Centers for Disease Control and Prevention (CDC) 2000 growth charts, age- and sex-specific BMI percentiles were calculated. CDC growth standards were used as research supports their validity for United States children 2 years of age and older as compared with WHO standard curves (De Onis, 2007). Age- and sex-specific BMI percentiles were categorized into four groups: underweight (<5th percentile), healthy weight (5.0th – 84.9th percentile), overweight (85.0th – 94.5th percentile) and obese (\geq 95.0th percentile).

Specific Aim 2 investigated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with the BMI trajectories of DMBC children from 2 to 8 years old. BMI trajectory was defined as rate of change in BMI (kg/m²/month) from ages 2 to 8 years. The rate of change was computed by calculating visit-specific BMI for children with two or more primary care encounters between 2 and 8 years of age for each visit.

A maximum of 7 scheduled visits (2-year, 3-year, 4-year, 5-year, 6-year, 7-year and 8-year) informed BMI trajectories and varied by year of birth. **Table 3-4** presents visit schedule by year of follow-up and birth year cohort. The visit number for each child was calculated as the sum of the number of well-child encounters between 2 and 8 years. Inclusion criteria for this analysis did not require contiguous or annual visits but rather that each child had at least 2 visits between ages 2 and 8 years. For example, children with 2 well-child visits could have been followed for anywhere between 1 year (visit at age 2 and visit at age 3) or 6 years (visit at age 2 and visit at age 8). As a result, total visit number was evaluated as a crude measure of adherence to well-child care rather than as a proxy for duration of follow-up. Follow-up time was calculated as the difference in DMBC

child age (months) between the last well-child encounter between 2 and 8 years and first visit well-child encounter between 2 and 8 years.

Descriptive analysis was performed to evaluate the association between visit count and cohort year. The mean visit counts and follow-up times for each birth cohort is presented in **Table 3-5**. The average visit number for the 2007 cohort was 3.4 visits/child which was approximately 2 visits/child less than that for the 2004 cohort (mean = 5.3). Consistent with differential follow-up eligibility by birth cohort, children born in 2004 were followed for over 60 months whereas those born in 2007 were followed for just over 30 months.

BMI trajectories were calculated for all children with at least 2 well-child visits, regardless of the time-interval between visits. A scatter plot of BMI was graphed by age for each child included in the DMBC. Children with a calculated BMI that was ± 5 standard deviations from the mean at any age were evaluated individually to ensure biologic plausibility and to assess for data entry errors of height and weight values used to compute the BMI. For the 16 children with outlying BMI calculations at any age ($n = 10$ for 2-year old visit, $n = 3$ for 3-year old visit, $n = 1$ for 4-year old visit, $n = 2$ for 5-year visit), each had at least three documented primary care visits. For each child, the extreme value was considered missing and trajectories were re-calculated based on the remaining encounter data. No maternal-child pairs were excluded from this analysis because of outlying growth trajectories.

Stata 13 statistical software (*Stata Statistical Software: Release 13*. College Station, TX) was used to create the best fit line for each child using least squares regression. The rate of BMI change from 2 to 8 years was converted to an ordinal variable with four categories: decline, stable, steady gain and rapid gain. The

development of this variable was informed by previous research guiding break points for BMI change (Cole, 2005) as well as by the ease of interpretation and practical utility of a BMI change measure. Children with an average decrease in BMI greater than 0.05 kg/m²/month were categorized in the decline group. Children who did not lose or gain more than 0.05 kg/m²/month were categorized in the stable group. Children who gained between 0.05 and 0.1 kg/m²/month were categorized in the steady gain group. Children who gained over 0.10 kg/m²/month were categorized in the rapid gain group.

Multiple analyses were performed to determine the validity of this variable. The mean weight (kg, **Table 3-6**) and height (m, **Table 3-7**) for each trajectory category (decline, stable, steady gain and rapid gain) were evaluated at 2, 4, 6 and 8 years old to determine the face validity of the dependent variable. The average weight gain by BMI trajectory category ranged from 2.68 kg/year in the declining BMI trajectory group to 5.68 kg/year in the rapid gain BMI trajectory group. When evaluating average height gain by BMI trajectory category, children categorized by BMI decline grew 6.55 cm/year whereas those categorized by rapid gain BMI grew 7.34 cm/year, a group difference of only 0.79 cm/year.

The average BMI for each BMI trajectory category at ages 2, 4, 6 and 8 are shown in **Table 3-8**. The average annual BMI change in the decline trajectory group was -0.62 kg/m²/year, 0.02 kg/m²/year in the stable group, 0.70 kg/m²/year in the steady gain group and 1.5 kg/m²/year in the rapid gain group. Evaluation of these trends suggests that the change in BMI in the steady and rapid gain groups can be attributed to accelerated weight gain among these children rather than stunted height.

Because the final BMI trajectory categories were based on maternal-child pairs from various birth cohorts with differential visit count and length of follow-up, analyses was performed to evaluate the association between visit count, follow-up time and BMI trajectory category.

Mean visit number for each BMI trajectory category was calculated. Average visit count for children in the stable, steady gain and rapid gain groups was about 4.5 versus just over 3.0 for the decline trajectory group. One-way ANOVA was performed to determine whether there was a significant difference in visit number by trajectory group (**Table 3.9**) ($p < 0.001$). Follow-up time for the decline group was significantly different than the stable, steady gain and rapid gain trajectory groups based on pair-wise comparisons performed using the Tukey Post-Hoc test (**Table 3-10**). No other pairwise comparisons were identified between the stable, steady gain and rapid gain trajectories. For further characterization, the study sample was divided based on visit count (2 NCHS visit, 3 NCHS visit, etc.) and cross-tabulated by BMI trajectories category. The sample distributions based on visit frequency are presented in **Table 3-11**. Evaluation of trends in visit data reveal that 92.9% of children categorized in the decline trajectory group had 4 or less well-child visits.

Like visit count, mean follow-up time for each BMI trajectory category was calculated. Average follow-up time was 32.4 months for the decline trajectory, 47.9 months for the stable trajectory, 48.5 months for the steady gain trajectory and 51.0 months for the rapid gain trajectory. One-way ANOVA was performed to determine whether there was a significant difference in follow-up time by trajectory group. (**Table 3-12**) ($p < 0.001$). Mean follow-up time was found to be significantly different for the decline trajectory than the stable, steady gain or

rapid gain groups based on pair-wise comparisons performed using the Tukey Post-Hoc test (**Table 3-13**). In addition, there was a significant difference in follow-up time between the stable and rapid gain groups. No other pair-wise comparisons were statistically significant.

Criterion validity was evaluated by comparing percentages (χ^2 test of independence) of each BMI trajectory group that crossed < 2 or ≥ 2 major weight-for-length percentiles, a measure associated with later obesity (Taveras, 2011). Results are presented in **Table 3 - 14**. Almost half of children with BMI trajectories categorized as steady or rapid gain crossed at least 2 major weight-for-length percentiles compared to 28.0% of children in the stable trajectory and 3.1% of children in the decline trajectory groups.

These data suggest potential surveillance bias for children with trajectories characterized by BMI decline. It is possible that children with declining trajectory have concomitant disease that alters growth and thus, are followed more closely by subspecialty providers than by general pediatricians. To account for variability in visit number by BMI trajectory, and the correlation between birth cohort and visit number, birth years was included in subsequent analyses. Because length of follow-up was associated with BMI trajectory, follow-up duration was converted to a categorical variable (≤ 36 months, 37 - 60 months, > 60 months) and included in subsequent analyses.

Maternal characteristics

Maternal characteristics included attributes known to be associated with pre-pregnancy BMI, children's BMI or child growth trajectory. Maternal socio-demographic characteristics were race/ethnicity, marital status, education, insurance status and parity. Race was self-identified and categorized using CCHS obstetric medical

record as white/Caucasian (reference), black/African-American, non-white Hispanic, Asian and other. Marital status was a dichotomous variable defined as married (reference) or unmarried. The unmarried category included women who self-reported single/never married, divorced or widowed. Maternal education was self-reported and categorized as non-high school graduate, high school graduate (reference) or any college. Insurance status was determined based on payment codes in the CCHS delivery registration system and defined as private (reference) and public insurance; public insurance included Medicaid, TriCare and self-pay/uninsured. Parity was defined as the number of living child of the DMBC women and ranged from 0 to 10. It was categorized as no living children (reference) and one or more living child.

Maternal pre-pregnancy health characteristics included pre-pregnancy BMI, chronic hypertension, pre-pregnancy diabetes mellitus and smoking history. Maternal pre-pregnancy BMI was calculated as self-reported pre-pregnancy weight divided by the square of the height (kg/m^2). Maternal pre-pregnancy BMI was dichotomized into women with $\text{BMI} < 30 \text{ kg/m}^2$ (underweight, normal or overweight, reference) or $\text{BMI} \geq 30 \text{ kg/m}^2$ (obese). Chronic hypertension, diabetes mellitus and smoking were as defined as dichotomous variables, present or absent (reference). Chronic hypertension was defined as a documented diagnosis of hypertension antecedent to the DMBC pregnancy. Diabetes was defined as a documented diagnosis of type I or II diabetes that predated the DMBC pregnancy. Smoking was self-reported and considered present if the DMBC mother reported ever smoking prior to the DMBC pregnancy.

Maternal health characteristics during pregnancy were gestational diabetes and pregnancy-associated hypertensive disorder. Gestational diabetes and pregnancy-associated hypertensive disorder were both

defined as dichotomous variables, present or absent (reference). Gestational diabetes was defined as a failed 3-hour glucose screening test between 24 - 28 weeks of gestation. Pregnancy-associated hypertensive disorders included pregnancy-induced hypertension, pre-eclampsia, eclampsia and Hemolysis Elevated Liver Enzymes Low Platelets (HELLP) syndrome. Birth weight was included as a newborn characteristic, measured in grams (g) and was categorized as very low birth weight (< 1500 g), low birth weight (1500 - 2500 g), normal weight (2500 - 4000 g) and high birth weight (> 4000 g).

Community Exposures/Independent variables

Community characteristics were derived from the US census (census-tract deprivation) and the FRD (neighborhood food environment). A measure of census-tract deprivation was created using principal components analysis (PCA). The methodology employed was informed by the work of Messer *et al*, 2006 (Messer, 2006). A total of 20 variables that have been frequently used to characterize neighborhood environment were abstracted from the US census. These variables fall into 7 broad socioeconomic and demographic domains - poverty, education, occupation, housing, employment, residential stability and racial composition - consistently associated with health outcomes (Messner, 2006).

Data were reduced using PCA to determine the total census tract-level variance explained by the 20 variables in Delaware (**Table 3-15**). Because the aim of the analysis was to identify a single principal component which explained the greatest percentage of variability in socioeconomic deprivation between tracts, only the first component was used. Of the 20 census-tract variables, 14 variables had factor loadings < -0.20 or > 0.20. These 14 variables are italicized in **Table 3-15**. The PCA was re-estimated with these 14 variables and standardized

by dividing the index by the square of the eigenvalue to achieve a mean of 0 and standard deviation of 1. The final principal component explained 67.98% of the variability of the index. Quintiles (minimal deprivation (reference), mild deprivation, moderate deprivation, high deprivation and extreme deprivation) were created from the continuous neighborhood deprivation index.

Two analyses were performed to assess the content validity of the index. First, z-tests of multiple proportions were performed to evaluate differences in participation in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) in relation to the created census-tract deprivation index (**Table 3-16**). Second, ANOVA was performed to assess the average median household income in each census-tract deprivation index category (**Table 3-17**). There was a statistically significant association between deprivation category and both WIC participation and median census-tract income. WIC participation was directly associated with deprivation category; only 13.88% of DMBC mother-child pairs who resided in census-tracts with minimal deprivation received benefits compared to over 50% (52.36%) of their maternal-child counterparts who resided in census-tracts with extreme deprivation. The average median-tract household income was inversely related to deprivation with mean income of \$101,434.80 in the minimally deprived tracts versus \$36,178.26 in extremely deprived tracts.

The Delaware Healthy Toolkit Food Resource Database (FRD) was used to identify healthy food outlets in the State. Of the 190 retailers included in the FRD, 182 were confirmed to be active businesses for at least 24 months during the study period. The straight-line distances between each food outlet and the address of each maternal-child pair were calculated. The single food outlet with

the shortest distance to each maternal-child pair was identified and included in the analysis for the pair. Distance between residence and food outlet was considered close if it was < 0.5 miles (reference) and far if it was ≥ 0.5 miles.

Analytic methods

For Aim 1, summary statistics were calculated for the outcome and all independent variables under investigation. Second, the sample was stratified by each of the three main independent variables to assess the association between maternal pre-pregnancy BMI, census-tract deprivation and neighborhood food environment with maternal sociodemographic, pre-pregnancy health and pregnancy characteristics. Third, bivariable analyses were conducted using the Pearson χ^2 statistic to evaluate the association between BMI percentile category at age 5 and each independent variable. Pre-pregnancy BMI-specific percentages of childhood underweight, normal weight, overweight and obese were calculated to evaluate for differences in percentage of childhood weight status by maternal pre-pregnancy BMI. Simple multinomial regression was used to estimate unadjusted odds ratio (OR) and 95% confidence interval of BMI percentile category for each significant covariable. Maternal pre-pregnancy BMI, census-tract neighborhood deprivation and neighborhood food environment, as well as each covariate found to be statistically significant in bivariable analyses were included in regression models.

For all multivariable analyses, maternal and child characteristics were considered nested within neighborhoods (census-tract); thus, multi-level modeling was employed. Multivariable multinomial logistic regression was performed to identify the independent influence of maternal pre-pregnancy BMI, neighborhood food

environment and census-tract socioeconomic deprivation on child BMI percentile at 5-years after adjusting for covariates. A block-based sequential modeling approach was performed to assess potential confounding of the association between maternal pre-pregnancy BMI and childhood BMI percentile by sets of variables.

Model 1: pre-pregnancy BMI +
community characteristics

Model 2: pre-pregnancy BMI +
community characteristics +
socio-demographic characteristics

Model 3: pre-pregnancy BMI +
community characteristics +
socio-demographic characteristics +
pre-pregnancy health characteristics

Model 4: pre-pregnancy BMI +
community characteristics +
socio-demographic characteristics +
pre-pregnancy health characteristics +
pregnancy health characteristics

The multivariable multinomial model is expressed by the following equation:

$$\ln\left[\frac{Y_i = m_x}{Y_i = BMI_{normal}}\right] = a_m + \sum_{k=1}^k \beta_{mk} X_{ik}$$

Where:

m_1 = BMI percentile category:
underweight (<5th percentile)
overweight (85.0th – 94.5th percentile)
obese (≥ 95.0th percentile)

a_m = intercept

β = log odds ratio for variable k, category i relative to reference; adjusting for all other variables

e^{β} = odds ratio for variable k, category i relative to reference, adjusting for all other variables

The model can be expanded to represent the multi-level nature of the data as follows:

$$\text{Level 1: } Y_{ij} = \beta_{0j} + \beta_{1j}(X_{1ij} - X_{ij}) + \gamma_{ij}$$

$$\text{Level 2: } \beta_{1j} = \gamma_{01} + \mu_{ij}$$

Where:

Level 1: individual level analysis

Level 2: census-tract level analysis

i = mother-child

j = census-tract covariate

β_{1j} = random-slope for multivariable equation

Model fit was assessed using several approaches. The likelihood ratio R^2 was estimated to determine the predictive power of each multinomial model. Pearson χ^2 statistic and the deviance were computed to determine improvements in goodness-of-fit with the addition of each category of covariates.

For all analyses, $p\text{-value} < 0.05$ was considered statistically significant. All analyses were performed using Stata/IC Version 13.0 (*Stata Statistical Software: Release 13*. College Station, TX) and Comprehensive R Archive Network (R) Version 3.4.2 (*R Foundation for Statistics Computing: Release 3.4.2*, Vienna, Austria). LaTeX (*The*

LaTeX project: LaTeX2e, Mainz, Germany) was used to prepare the dissertation. Sweave was used to integrate R statistical programming into the LaTeX formatted document.

The statistical approach for Aim 2 paralleled that for Aim 1 with slight modifications and supplemental analyses given the longitudinal outcome under evaluation. Bivariable hypothesis testing and multinomial regression modeling was performed to evaluate independent variables significantly associated with BMI trajectory category of DMBC children from ages 2 to 8 years. Main predictor variables as well as covariates significant in the bivariable analysis were regressed on BMI trajectory category in a block-based approach to evaluate for potential confounding. Model fit was assessed using the likelihood ratio R^2 , Pearson χ^2 statistic and the deviance.

The multivariable multinomial model for specific aim 2 is expressed by the following equation:

$$\ln\left[\frac{Y_i = m_x}{Y_i = BMI_{normal}}\right] = a_m + \sum_{k=1}^k \beta_{mk} X_{ik}$$

Where:

m_2 = Change in BMI 2- 8 years:

decline (< -0.05 kg/m²/month)

stable (-0.05 to 0.05 kg/m²/month)

steady gain (0.05 to 0.10 kg/m²/month)

rapid gain (> 0.10 kg/m²/month)

a_m = intercept

β = log odds ratio for variable k, category i relative to reference; adjusting for all other variables

e^β = odds ratio for variable k, category i relative to reference, adjusting for all other variables

Additional Analyses

Supplemental analyses were performed to better understand the association between maternal pre-pregnancy BMI and community characteristics, neighborhood food environment and census-tract socioeconomic deprivation. Maternal pre-pregnancy BMI was the outcome under investigation and was modeled as a dichotomous variable (BMI < 30 kg/m²; BMI ≥ 30 kg/m²) for the supplemental analysis. Simple and multivariable logistic regression was used to estimate the unadjusted and adjusted odds ratios of maternal pre-pregnancy obesity as a function of each neighborhood characteristics (census-tract deprivation and food environment) as well as covariates known to be associated with weight status among reproductive women. Covariates included in this analysis were race, marital status, education, insurance, parity, age, chronic hypertension, diabetes mellitus, smoking history.

Ethical Considerations

The DMBC is a preexisting database; this research relied exclusively on secondary analysis of data. All data analyses prior to September 2016 were performed under the jurisdiction of the Christiana Care Health System IRB. The principal investigator of the DMBC, Deborah Ehrenthal, MD, MPH transitioned the study IRB to the University of Wisconsin - Madison (UW-M) in September 2016. All analyses since that time were performed under the jurisdiction of the UW-M School of Medicine IRB. A copy of both the CCHS and the UW-M IRBs were provided to the Office of Research Ethics at the Johns Hopkins Bloomberg School of Public Health (IRB-X) to conform to all data procurement, management and analysis procedures set forth therein.

The main risk involved in this study was potential breach of patient confidentiality as outlined in the Health Information

Portability and Accountability Act (HIPAA). While geocoded data were included in the core DMBC dataset, special precautions were implemented to ensure protection of patient information. All files used for data management and analyses were saved on an encrypted external hard-drive (IronKey). All geospatial data were kept in separate files from health information data and linked by a study specific identifier. After all neighborhood-level indicators were merged with DMBC data, unique identifiers were removed from the analytic data file. In addition, all data files and hard-drives were password protected.

Figure 3-1: Timeline for maternal and child enrollment into the Delaware Mother and Baby Cohort

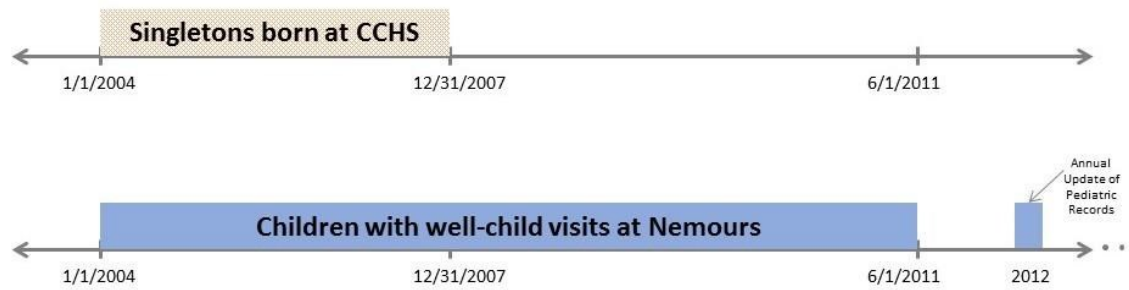


Table 3-1: Maternal delivery and socio-demographic characteristics in United States, Delaware and Christiana Care Health System (CCHS), 2010 - 2017

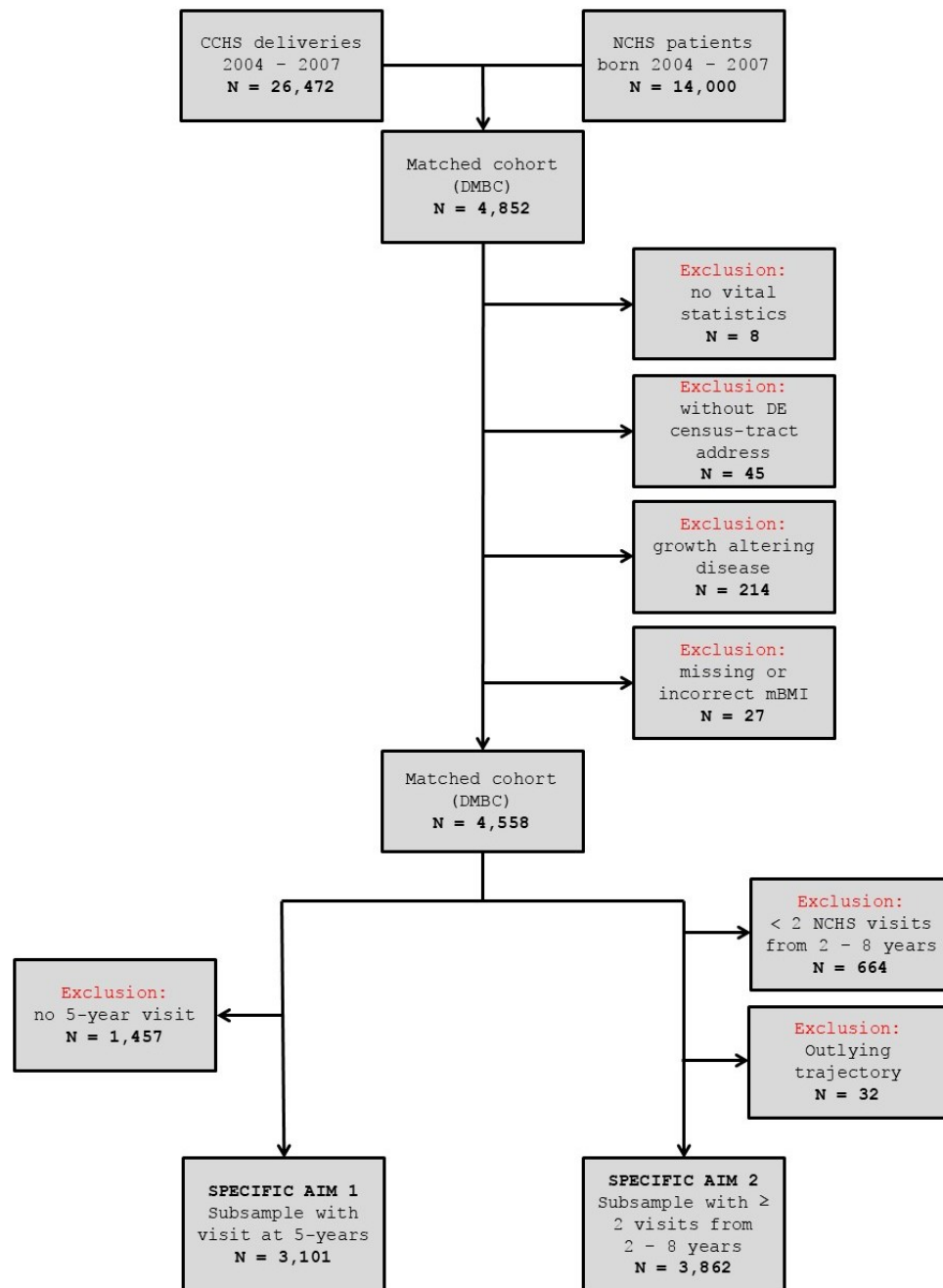
| | US | Delaware | CCHS |
|----------------------------|------|----------|------|
| Age at first birth (years) | 25.0 | 25.0 | 26.0 |
| Unmarried mothers (%) | 38.5 | 45.5 | 38.0 |
| Preterm birth (%) | 12.8 | 13.7 | 13.6 |
| Cesarean Delivery (%) | 31.1 | 30.7 | 33.0 |
| Race/ethnicity* | | | |
| White (%) | 53.0 | 53.0 | 58.0 |
| Black (%) | 15.0 | 27.0 | 24.0 |
| Hispanic (%) | 25.0 | 15.0 | 12.0 |
| Other (%) | 7.0 | 5.0 | 6.0 |
| Insurance status | | | |
| Private (%) | 71.6 | 77.7 | 64.0 |
| Public or Uninsured (%) | 28.4 | 22.3 | 36.0 |

* Hispanic is considered race

Table 3-2: Age and anthropometric characteristics of Delaware Mother and Baby Cohort (DMBC) children by American Academy of Pediatrics recommended visit

| AAP Visit | n (%) | Age (months) mean (sd) | Weight (kg) mean (sd) | Height (cm) mean (sd) |
|-----------|--------------|---------------------------|--------------------------|--------------------------|
| 2 weeks | 3389 (69.85) | 0.30 (0.15) | 3.34 (0.52) | 49.48 (2.57) |
| 1 month | 2290 (47.20) | 1.07 (0.18) | 4.17 (0.75) | 52.47 (5.04) |
| 2 month | 3555 (73.27) | 2.08 (0.31) | 5.20 (0.83) | 56.12 (3.22) |
| 4 months | 3575 (73.68) | 4.13 (0.40) | 6.71 (0.98) | 61.93 (3.24) |
| 6 months | 3617 (74.55) | 6.28 (0.53) | 7.85 (1.05) | 66.17 (3.01) |
| 9 months | 3531 (72.77) | 9.18 (0.68) | 8.93 (1.14) | 70.47 (3.30) |
| 12 months | 3510 (72.34) | 12.24 (0.60) | 9.84 (1.21) | 74.49 (3.07) |
| 15 months | 3331 (68.65) | 15.17 (0.73) | 10.58 (2.00) | 77.84 (5.07) |
| 18 months | 3573 (73.64) | 18.57 (1.05) | 11.35 (1.49) | 81.35 (4.14) |
| 2 years | 3993 (82.30) | 25.42 (2.50) | 12.84 (2.41) | 87.45 (6.08) |
| 3 years | 3874 (79.84) | 36.26 (2.71) | 15.41 (2.94) | 96.64 (4.74) |
| 4 years | 3853 (79.41) | 50.46 (2.83) | 17.86 (2.96) | 104.40 (4.93) |
| 5 years | 3467 (71.46) | 62.19 (3.86) | 20.42 (3.89) | 111.20 (5.31) |
| 6 years | 2455 (50.60) | 74.02 (3.03) | 23.40 (5.13) | 117.64 (5.70) |
| 7 years | 1499 (30.89) | 85.78 (3.00) | 27.13 (6.93) | 123.80 (5.92) |
| 8 years | 663 (13.36) | 97.07 (2.80) | 30.80 (8.35) | 129.74 (6.30) |

Figure 3-2: Study sample flow diagram for aims 1 and 2



Christiana Care Health System (CCHS); Nemours Children's Health System (NCHS); Delaware Mother and Baby Cohort (DMBC); Maternal body mass index (mBMI)

Table 3-3: Summary of variables for specific aims 1 and 2

| Variable | Measurement | Data source |
|---|--|--------------------------------|
| Outcome | | |
| BMI percentile at age 5 * | Categorical Unit: percentile < 5 th Underweight 5 - 84.9 th Normal weight (ref) 85 - 94.9 th Overweight ≥ 95 th Obese | NCHS Electronic Medical Record |
| Change in BMI 2 - 8 years ** | Categorical Unit: kg/m ² /month > -0.05 Decline -0.05 - 0.05 Stable (ref) 0.05 - 0.10 Steady gain ≥ 0.10 Rapid gain | NCHS Electronic Medical Record |
| Maternal socio-demographic characteristics | | |
| Race | Categorical Caucasian/white (ref) Black/African-American Hispanic, non-Caucasian Asian Unknown | Birth Certificate |
| Marital status | Categorical Single, widowed, divorced (ref) Married | Birth Certificate |
| Education | Categorical Less than high school High school graduate (ref) Any college | Birth Certificate |
| Insurance | Categorical Private (ref) Public (Medicaid, Tricare or Uninsured) | Birth Certificate |
| Parity | Categorical Nulliparous Multiparous (ref) | CCHS Electronic Medical Record |
| Age | Categorical < 18 years 18 - 34 years (ref) > 35 years | CCHS Electronic Medical Record |
| Maternal pre-pregnancy health characteristics | | |
| Pre-pregnancy BMI | Categorical Unit: kg/m ² < 30 Underweight, normal or overweight (ref) ≥ 30 Obese | CCHS Electronic Medical Record |
| Chronic hypertension | Categorical Yes/No (ref) | CCHS Electronic Medical Record |
| Diabetes mellitus | Categorical Yes/No (ref) | CCHS Electronic Medical Record |
| Smoking history | Categorical Yes/No (ref) | Birth Certificate |
| Pregnancy health characteristics | | |
| Gestational diabetes | Categorical Yes/No (ref) | CCHS Electronic Medical Record |
| Pregnancy related hypertensive disorder | Categorical Yes/No (ref) | CCHS Electronic Medical Record |
| Birth weight | Categorical < 1500 g 1500 - 2499 g 2500 - 3999 g (ref) > 4000 g | Birth Certificate |

| | | |
|-------------------------------|---|--------------------------------|
| Community characteristics | | |
| Census-tract deprivation | Categorical Minimal (ref) Mild Moderate High Extreme | U.S. Census |
| Neighborhood food environment | Categorical Unit: miles < 0.5 (ref) ≥ 0.5 | Delaware Healthy Toolkit |
| Cohort characteristics | | |
| Visit count ** | Categorical Unit: number of well-child visits 1, 2, 3, 4, 5, 6, 7 | NCHS Electronic Medical Record |
| Follow-up ** | Categorical Unit: months ≤ 36 months, 37 - 60 months, > 60 months | NCHS Electronic Medical Record |

* Specific aim 1 only

** Specific aim 2 only

**Table 3-4: Delaware Mother and Baby Cohort (DMBC) well-child visit
schedule by year of follow-up and birth year cohort**

| Birth Year | Age (years) | | | | | | |
|---------------|-------------|------|------|------|------|------|------|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2004 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| 2005 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | |
| 2006 | 2008 | 2009 | 2010 | 2011 | 2012 | | |
| 2007 | 2009 | 2010 | 2011 | 2012 | | | |

**Table 3-5: Delaware Mother and Baby Cohort (DMBC) children visit counts
and follow-up time (months) from 2 to 8 years old**

| Birth Year | Visit Count mean (sd) | Follow-up Duration (months) Mean (sd) |
|------------|--------------------------|--|
| 2004 | 5.3 (1.5) | 61.3 (14.9) |
| 2005 | 4.8 (1.2) | 51.3 (12.6) |
| 2006 | 4.1 (1.0) | 42.1 (9.6) |
| 2007 | 3.4 (0.7) | 31.4 (7.5) |

**Table 3-6: Delaware Mother and Baby Cohort (DMBC) children weights (kg)
at 2-, 4-, 6- and 8-years old by body mass index (BMI) trajectory
category**

| | Weight (kg) mean (sd) | | | |
|-------------|--------------------------|--------------|--------------|---------------|
| | 2 years | 4 years | 6 years | 8 years |
| Decline | 13.50 (2.00) | 17.43 (2.59) | 21.38 (2.92) | 29.62 (10.77) |
| Stable | 12.69 (1.59) | 17.45 (2.30) | 22.16 (3.26) | 27.81 (4.49) |
| Steady gain | 13.30 (1.86) | 19.80 (3.27) | 28.25 (4.56) | 37.33 (5.68) |
| Rapid gain | 13.80 (2.09) | 23.00 (4.99) | 34.88 (7.50) | 47.93 (8.98) |

**Table 3-7: Delaware Mother and Baby Cohort (DMBC) children height (cm)
at 2-, 4-, 6- and 8-years old by body mass index (BMI) trajectory
category**

| | Height (cm) mean (sd) | | | |
|-------------|--------------------------|---------------|---------------|---------------|
| | 2 years | 4 years | 6 years | 8 years |
| Decline | 86.30 (6.17) | 104.02 (4.77) | 117.80 (7.79) | 125.59 (4.11) |
| Stable | 87.59 (3.80) | 104.31 (4.56) | 117.36 (5.26) | 128.85 (5.57) |
| Steady gain | 88.29 (3.99) | 105.75 (6.22) | 119.66 (5.14) | 132.24 (5.65) |
| Rapid gain | 90.64 (16.09) | 107.07 (5.01) | 121.63 (5.67) | 134.69 (5.94) |

Table 3-8: Delaware Mother and Baby Cohort (DMBC) children body mass index (BMI; kg/m²) at 2-, 4-, 6- and 8-years old by BMI trajectory category

| | BMI (kg/m ²) mean (sd) | | | |
|-------------|---------------------------------------|--------------|--------------|--------------|
| | 2 years | 4 years | 6 years | 8 years |
| Decline | 17.98 (2.07) | 16.07 (1.80) | 15.49 (1.69) | 14.21 (0.66) |
| Stable | 16.50 (1.40) | 15.99 (1.36) | 16.03 (1.54) | 16.64 (1.94) |
| Steady gain | 17.04 (1.97) | 17.68 (2.28) | 19.71 (2.39) | 21.23 (2.28) |
| Rapid gain | 17.32 (2.61) | 19.91 (3.30) | 23.49 (3.73) | 26.32 (3.30) |

Table 3-9: Delaware Mother and Baby Cohort (DMBC) children visit count between age 2 and 8 by child body mass index (BMI) trajectory group

| | Visit Count mean (sd) | <i>p</i> |
|-------------|--------------------------|----------|
| Decline | 3.2 (0.9) | <0.001 |
| Stable | 4.5 (1.3) | |
| Steady gain | 4.4 (1.5) | |
| Rapid gain | 4.6 (1.4) | |

Table 3-10: Pairwise comparison of Delaware Mother and Baby Cohort (DMBC) children visit count by child body mass index (BMI) trajectory group; Tukey post-hoc analysis

| | <i>p</i> -value | | | |
|-------------|-----------------|--------|-------------|------------|
| | Decline | Stable | Steady gain | Rapid gain |
| Decline | | | | |
| Stable | < 0.001 | | | |
| Steady gain | < 0.001 | 0.939 | | |
| Rapid gain | < 0.001 | 0.320 | 0.295 | |

**Table 3-11: Cross-tabulation of Delaware Mother and Baby Cohort (DMBC)
children body mass index (BMI) trajectory by number of well-child
visits from 2 - 8 years old**

| | n (%) | | | | | |
|-------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|
| | 2 visits | 3 visits | 4 visits | 5 visits | 6 visits | 7 visits |
| Decline | 80 (24.10) | 115 (16.50) | 107 (9.78) | 20 (2.22) | 3 (0.50) | 0 (0.00) |
| Stable | 196 (59.04) | 505 (72.45) | 880 (80.44) | 758 (84.32) | 508 (84.11) | 190 (80.51) |
| Steady gain | 41 (12.35) | 45 (6.46) | 69 (6.31) | 70 (7.79) | 59 (9.77) | 24 (10.17) |
| Rapid gain | 15 (4.52) | 32 (4.59) | 38 (3.47) | 51 (5.67) | 34 (5.63) | 22 (9.32) |
| Total | 332 (100.00) | 697 (100.00) | 1094 (100.00) | 899 (100.00) | 604 (100.00) | 236 (100.00) |

Table 3-12: Delaware Mother and Baby Cohort (DMBC) children follow-up time (months) between age 2 and 8 by child body mass index (BMI) trajectory group

| | Follow-up (months) mean (sd) | <i>p</i> |
|-------------|---------------------------------|----------|
| Decline | 32.4 (12.5) | <0.001 |
| Stable | 47.9 (15.2) | |
| Steady gain | 48.5 (18.0) | |
| Rapid gain | 51.0 (17.7) | |

Table 3-13: Pairwise comparison of Delaware Mother and Baby Cohort (DMBC) follow-up time (months) by child body mass index (BMI) trajectory group; Tukey post-hoc analysis

| | <i>p</i> -value | | | |
|-------------|-----------------|--------|-------------|------------|
| | Decline | Stable | Steady gain | Rapid gain |
| Decline | | | | |
| Stable | < 0.001 | | | |
| Steady gain | < 0.001 | 0.921 | | |
| Rapid gain | < 0.001 | 0.037 | 0.293 | |

**Table 3-14: Frequency of Delaware Mother and Baby Cohort (DMBC)
children crossing < 2 or ≥ 2 major weight-for-length percentiles by
body mass index (BMI) trajectory category**

| | n (%) | | |
|-------------|---------------|---------------------------|-------------------------------|
| | All | < 2 major percentile | ≥ 2 major percentiles |
| Decline | 325 (100.00) | 315 (96.92) | 10 (3.08) |
| Stable | 3037 (100.00) | 2188 (72.04) | 849 (27.96) |
| Steady gain | 308 (100.00) | 164 (53.25) | 144 (46.75) |
| Rapid gain | 192 (100.00) | 102 (53.13) | 90 (46.88) |
| Total | 3862 (100.00) | 2769 (71.70) | 1093 (28.30) |

Table 3-15: Census-tract variables and factor loadings informing the census-tract deprivation index

| Census-tract Variable | Factors Loading |
|---|-----------------|
| Education | |
| <i>Percent > 25 with less than a high school</i> | <i>0.2607</i> |
| Employment | |
| <i>Percent > 16 unemployed</i> | <i>0.2460</i> |
| <i>Percent of households with no work in last 12 months</i> | <i>-0.0216</i> |
| Housing | |
| <i>Percent of homes in census-tract renter occupied</i> | <i>0.2360</i> |
| <i>Percent of homes in census-tract unoccupied (vacant)</i> | <i>0.0406</i> |
| <i>Percent of homes in census-tract with >1 occupant/room</i> | <i>0.1837</i> |
| <i>Percent of households > 35% of income spent on mortgage/rent</i> | <i>0.2496</i> |
| <i>Median household value in tract</i> | <i>-0.2281</i> |
| Occupation | |
| <i>Percent of employed males > 16 in management jobs</i> | <i>-0.2295</i> |
| <i>Percent of employed males > 16 in service jobs</i> | <i>0.1924</i> |
| <i>Percent of employed females > 16 in management jobs</i> | <i>-0.2331</i> |
| <i>Percent of employed females > 16 in service jobs</i> | <i>0.2284</i> |
| Poverty | |
| <i>Percent of households living below federal poverty</i> | <i>0.2606</i> |
| <i>Percent of households with female householder, no husband present, living with related or own children</i> | <i>0.2787</i> |
| <i>Percent of households with 2010 annual income < \$35,000</i> | <i>0.2824</i> |
| <i>Percent of households with cash public assistance</i> | <i>0.2166</i> |
| <i>Percent of families receiving food stamps/SNP</i> | <i>0.2914</i> |
| Racial composition | |
| <i>Percent of population non-Hispanic black</i> | <i>0.2474</i> |
| Residential stability | |
| <i>Percent of population in same residence since 1999</i> | <i>-0.1786</i> |
| <i>Percent of population >65 years old</i> | <i>-0.1387</i> |

Table 3-16: Delaware Mother and Baby Cohort (DMBC) participation in the Special Supplemental Program for Women, Infants and Children (WIC) by deprivation category

| Deprivation category | WIC Participants* n (%) | | <i>p</i> |
|----------------------|----------------------------|-------------|----------|
| | No | Yes | |
| Minimal | 689 (86.13) | 111 (13.88) | < 0.001 |
| Mild | 552 (75.51) | 179 (24.49) | |
| Moderate | 578 (67.21) | 282 (32.79) | |
| High | 428 (57.76) | 313 (42.24) | |
| Extreme | 751 (45.74) | 891 (52.36) | |

* N = 4774; 4852 - 25 (no census) - 8 (no vital statistics) - 25 (unknown WIC status)

Table 3-17: Average median census-tract household income by deprivation category for census-tracts with residing Delaware Mother and Baby Cohort (DMBC) women and children

| Deprivation category | Household income* Mean (sd) | <i>p</i> |
|----------------------|--------------------------------|----------|
| Minimal | 101434.80 (20029.22) | <0.001 |
| Mild | 75527.76 (12006.72) | |
| Moderate | 61686.53 (10874.71) | |
| High | 53320.64 (6308.85) | |
| Extreme | 36178.26 (13746.51) | |
| Total | 60456.23 (26622.31) | |

* N = 4827; 4852 - 25 (no census)

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4. Results

The first aim of this study investigated the independent associations of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with child weight status at age 5. The second aim evaluated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with the BMI trajectories of DMBC children from 2 to 8 years old. In order to understand the association between maternal pre-pregnancy BMI and child obesity at 5-years and maternal pre-pregnancy BMI and childhood BMI trajectory from 2 to 8 years old, the direction and strength of the relation between maternal pre-pregnancy BMI and census-tract socioeconomic deprivation as well as between maternal pre-pregnancy BMI and neighborhood food environment were evaluated. This chapter includes the results for both specific aims as well as the supplemental analysis about the relations among the above factors.

Specific Aim 1

Aim 1 investigated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on child weight status at age 5. A total of 3101 maternal-child pairs were included in the analytic sample for Aim 1. The dependent variable was the age- and sex-standardized BMI percentile for DMBC children at 5 years-old; 95 (3.1%) children were classified as underweight (< 5th percentile), 2051 (66.1%) as normal weight (5th - 84.9th percentile), 542 (17.5%) as overweight (85th - 94.9th percentile), and 413 (13.3%) as obese (> 95th percentile).

Table 4-1 presents the distribution of child BMI percentile at age 5 as well as the maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics of the sample. Mothers who met inclusion criteria for Aim 1 were similar to all women included in the DMBC. Most women self-identified as either Caucasian/White (40.0%) or Black/African-American (45.8%) and less than half were married (45.2%). Most women were multiparous (65.1%) and between ages 18 and 34 years (82.6%). Educational attainment of the sample varied; more than 4 in 10 sample mothers had any college education (41.8%); however, just under one-quarter of study mothers had not graduated from high school (23.0%). Just over half of women were publicly insured (53.1%). A total of 797 (25.7%) women had a pre-pregnancy BMI ≥ 30 kg/m² and 637 (20.5%) ever smoked before the DMBC pregnancy.

The prevalence of pre-gestational diabetes was 1.0% and of chronic hypertension, 3.8%. The percentage of women with pre-gestational diabetes was consistent with population-based cohort studies among similar populations citing prevalence between 0.7% and 1.5% (Feig, 2014; Fong, 2014, Martin, 2016). Similarly, prevalence of chronic hypertension in our cohort was similar to other studies noting between 1% and 5% of pregnancies complicated by pre-pregnancy hypertension (Bramham, 2014; Haddad, 1999; Livingston, 2001; Roberts, 2008). A total of 201 (6.5%) women were diagnosed with gestational diabetes and 225 (7.3%) with a pregnancy associated hypertensive disorder (pregnancy induced hypertension, pre-eclampsia, eclampsia or HELLP syndrome) during the DMBC pregnancy.

Most women delivered normal birth weight babies (n = 2605; 84.0%) with 284 (9.2%) newborns < 2500 grams (g) and 212 (6.8%) newborns \geq 4000 g. While a greater percentage of children were born low

birthweight in our sample (8.0% of US children < 2500 grams in 2012), the percentage of children born \geq 4000 grams in our sample was similar to national estimates (6.8%) (Martin, 2016). Almost half of DMBC mothers resided in neighborhoods with high (n = 448; 14.4%) or extreme (n = 1069; 34.5%) deprivation and in homes greater than 0.5 miles away from the closest healthy food outlet (n = 2306, 74.4%).

Table 4-2 summarizes the relation of maternal socio-demographic, pre-pregnancy health, pregnancy health, and community characteristics with maternal pre-pregnancy BMI. Maternal pre-pregnancy BMI was significantly associated with maternal race, marital status, educational attainment, insurance, parity, age, chronic hypertension, diabetes mellitus, gestational diabetes, pregnancy associated hypertensive disorder, census tract deprivation and neighborhood food environment. Black/African-American (32.3%) women had a higher percentage of obesity than their Caucasian/White (19.4%) or Hispanic, non-Caucasian (24.3%) counterparts. About one-third (32.2%) of high school educated women were obese compared to about one-fourth of less educated women (23.0%) and just over 20% of women with any college education (21.7%). Almost 30% of multiparous women (28.0%) were obese compared to just over 20% of nulliparous women. Over half of women with chronic hypertension (55.9%), diabetes mellitus (53.3%) and gestational diabetics (50.7%) were obese. The maternal obesity percentage increased with higher levels of census-tract deprivation; only 13.0% of women in minimal deprivation tracts were obese compared with 30.6% in extremely deprived tracts. Women who lived greater than 0.5 miles from the nearest healthy food outlet had a slightly higher percentage of obesity (27.6%) compared to those that lived at most 0.5 miles away (25.1%)

Table 4-3 summarizes the association of neighborhood food environment with maternal socio-demographic characteristics, pre-

pregnancy health, pregnancy health, and census-tract socioeconomic deprivation. Overall, 25.6% of the sample mothers lived less than 0.5 miles from a healthy food outlet. Maternal socio-demographic characteristics associated with living < 0.5 miles from a healthy food outlet were Black/African-American race (34.7%); being single, widowed or divorced (34.1%); having less than high school diploma (31.7%); public insurance (33.4%) and age at delivery < 18 years (34.6%). A higher percentage of women who reported ever smoking lived < 0.5 miles from a healthy food outlet (30.5%) as compared to women who never smoked (24.4%). Of the women who resided in census-tracts characterized by extreme levels of community deprivation, 45.2% lived within 0.5 miles of a healthy food outlet as compared to 16.0% of women who lived in census-tracts with minimal deprivation. Finally, women whose newborns weighed less than 1500 grams were more likely to live near healthy food outlets (48.9%). There was no difference in maternal pre-pregnancy BMI by proximity to healthy food outlet.

Table 4-4 summarizes the relation of census-tract socioeconomic deprivation with maternal socio-demographic characteristics, pre-pregnancy health, pregnancy health, and neighborhood food environment. Census-tract deprivation was associated with race, marital status, educational attainment, insurance status, age, pre-pregnancy BMI, smoking history, pregnancy associated hypertensive disorder, birth weight and neighborhood food environment. Overall, 34.5% of the study sample lived in census tracts characterized by extreme deprivation. Living in these census-tracts was associated with Black/African-American maternal race (56.0%), being single, widowed or divorced (51.3%), having less than high school graduation (55.7%), public insurance (51.4%) and maternal age at delivery < 18 years (62.1%). The majority (61.4%) of women who reported ever smoking inhabited census-

tracts with high (17.3%) or extreme (44.1%) levels of deprivation. Women whose newborns weighed less than 1500 grams (42.6%) and between 1500 and 2499 grams (41.3%) were more likely to reside in neighborhoods characterized by extreme deprivation than women whose newborns weighed 2500 - 3599 grams (32.0%) and ≥ 4000 g (17.9%). Over 4 in 10 women with a pre-pregnancy BMI ≥ 30 kg/m² lived in extremely deprived census-tracts as compared to 32.2% of their counterparts with BMI < 30 kg/m².

Hypothesis testing was performed using Pearson's χ^2 Test of Independence to evaluate the null hypothesis of no difference in child BMI percentile category at 5-years between levels of independent variables. Results are summarized in **Table 4-5**. Statistically significant associations were identified between child BMI percentile category and maternal race, marital status, education, insurance, parity, maternal pre-pregnancy BMI, gestational diabetes, birth weight and census-tract deprivation. The percentage of childhood underweight, normal weight, overweight and obese were calculated for children of women with pre-pregnancy BMI < 30 kg/m² as well as for women ≥ 30 kg/m² (**Table 4-6**). Among women with a BMI ≥ 30 kg/m², 61.5% of women less than 18 years old had children $\geq 95^{\text{th}}$ percentile at age 5 as compared to 12.2% of women with pre-pregnancy BMI < 30 kg/m². In addition, women with a BMI ≥ 30 kg/m² had a higher percentage of children categorized as obese at 5 years than women with a pre-pregnancy < 30 kg/m² at every strata of neighborhood deprivation.

The strength of the association of each main predictor variable (maternal pre-pregnancy BMI, census-tract deprivation and food environment) and each statistically significant covariate with child weight status in χ^2 analysis was evaluated with simple multinomial logistic regression; results are presented in **Table 4-7**. All odds

ratios were calculated with normal BMI percentile (5th - 84.9th percentile) at 5 years-old as the reference category.

Maternal socio-demographic characteristics associated with child BMI at age 5 included race/ethnicity, education, insurance status and parity. Black/African-American and Hispanic non-Caucasian races were associated with increased odds of obesity when compared to children of White/Caucasian women; however, there was no association between either racial or ethnic category and underweight or overweight BMI. Children of Asian mothers had an over 300% increased odds of underweight BMI at age 5 when compared to children of their Caucasian/White counterparts though no increase or decrease in odds of overweight or obesity was observed. Children of women with any college education had decreased odds of obesity when compared to women with a high school education, but no other association between maternal education and childhood BMI status was significant. Children of women who were publicly insured at the time of delivery had 46% increased odds of obesity at 5 years old when compared to children of privately insured women; however, no association was observed between maternal insurance status and underweight or overweight BMI at 5 years old. Children of nulliparous women had 59% higher odds of underweight than those of multiparous women. No association between parity and overweight or obesity was observed.

The children of women with a pre-pregnancy BMI ≥ 30 kg/m² had over twice the odds (OR = 2.04; 95% CI: 1.65 - 2.51) of being overweight as compared to their counterparts with mothers whose pre-pregnancy BMI was < 30 kg/m². Odds of childhood obesity was over three-times higher (OR = 3.46; 95% CI: 2.78, 4.32) in children of women with pre-pregnancy obesity than in children of women who began pregnancy with a BMI < 30

kg/m². No association between maternal pre-pregnancy BMI and underweight at 5 years old was observed.

Pregnancy health characteristics found to be associated with child BMI category at age 5 included gestational diabetes and birth weight. Gestational diabetes was associated with obesity in children at 5 years old but was not associated with underweight or overweight BMI category. Birth weight < 1500 grams was associated with underweight but not overweight or obese categories. No other birth weight category was associated with BMI category among 5-year-old children.

While neighborhood food environment was not significantly related to child BMI in bivariable analyses, census-tracts characterized by mild, high and severe levels of deprivation were associated with obesity in 5-year-old DMBC children. No census-tract deprivation quintile was associated with underweight or overweight BMI categories.

A block-based sequential modeling approach was performed to assess potential confounding of the association between maternal pre-pregnancy BMI and childhood BMI percentile by sets of variables. The reference category for the dependent variable for all odds ratios was normal weight children. Results of the multivariable multinomial analysis are presented in **Tables 4-8, 4-9 and 4-10. Table 4-8** presents results for underweight versus normal weight children. The unadjusted odds ratio for the association between maternal pre-pregnancy BMI and child underweight was not statistically significant (aOR = 0.82, CI: 0.47, 1.41). There was no significant change in OR after adjusting for community characteristics, the aOR = 0.85 (CI: 0.50, 1.45) (Model 1). The addition of maternal socio-demographic characteristics results in a slight increase in aOR of 0.96 and thereby reflects some minor negative confounding by one or more of the variables included in this block. Given the strong association between maternal Asian race and maternal

pre-pregnancy BMI as well as the association between maternal Asian race and child underweight at 5-years, adjustment for this variable decreased the strength of the association between maternal pre-pregnancy BMI and child BMI at age 5. No pregnancy characteristics were found to be associated with child weight status at age 5 and thus, Model 3 was excluded. Model 4 represented the addition of pregnancy health characteristics to the block based model. Model 2 and Model 4 were nearly identical and thus, no additional confounding occurred with the addition of gestational diabetes status or birth weight.

Table 4-9 presents the results of the sequential block-based regression for overweight versus normal weight children. The unadjusted OR for the relation between maternal pre-pregnancy BMI and child overweight was 2.04. The adjusted odds ratios after addition of community characteristics (Model 1) was 2.03 reflecting no confounding between these variables. Model 2 included maternal socio-demographic variables and resulted in an increase aOR of 2.09 likely from a small negative confounding from parity. Model 3 was again excluded due to lack of significant maternal pre-pregnancy health variables. The addition of maternal pregnancy characteristics only slightly decreased the aOR to 2.05 with nearly identical results from Model 2.

Table 4-10 presents the results of the sequential multinomial regression model for the association between maternal pre-pregnancy BMI and child obesity at age 5. The unadjusted OR in simple multinomial regression was 3.46. Model 1 includes community characteristics and resulted in a decrease in aOR to 3.26 indicating a degree of positive confounding by one or more variables. Given the strong association between maternal pre-pregnancy BMI and census-tract deprivation as well as the association between census-tract deprivation and child weight status at age 5, the adjustment for this variable likely exposed the

weaker relation between maternal pre-pregnancy BMI and child weight status at age 5. The addition of maternal socio-demographic characteristics in model 2 results in a slight increase in aOR to 3.52 indicating some component of negative confounding by at least one variable included in this block. Given that Hispanic, non-Caucasian women had lower levels of obesity than their Black/African-American counterparts and that there was a strong association between maternal Hispanic, non-Caucasian race and child obesity, adjusting for race exposed a stronger relation between maternal pre-pregnancy BMI and child BMI at age 5. Model 4 included maternal pregnancy characteristics and was nearly identical to Model 2.

Table 4-11 presents the final multinomial regression model for specific aim 1. In adjusted models, maternal Hispanic non-Caucasian race/ethnicity was associated with obesity in 5-year-old children when compared to White/Caucasian race/ethnicity though it was not associated with underweight or overweight categories. Asian children had an over 250% increased odds of underweight compared to White/Caucasian race/ethnicity but they did not differ on overweight or obese BMI percentile categories. Children of women with less than high school education had increased odds of underweight but not of overweight or obesity at 5-years-old when compared with women with a high school education. Children of nulliparous women had increased odds of underweight, overweight and obesity when compared to children of multiparous women.

Maternal pre-pregnancy obesity was associated with increased odds of child overweight at 5 years old compared with children of non-obese women. The adjusted odds of obesity at 5 years was highest for children of obese women (OR = 3.56; 95% CI: 2.55 – 4.43) as compared to children of women with BMI < 30 kg/m². No association was observed between

maternal pre-pregnancy BMI and child underweight BMI category. Neither gestational diabetes nor birth weight was associated with child BMI category at 5-years-old in multivariable models.

When evaluating the independent influence of neighborhood characteristics, children of mothers living in extreme deprivation had 70% greater odds of obesity at 5-years old (OR = 1.70; 95% CI 1.05 - 2.75) compared to those living in census-tract characterized by minimal deprivation. Census-tract deprivation quintile was not otherwise associated with child BMI percentile category at age 5.

Specific Aim 2

Specific aim 2 investigated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with BMI trajectories of DMBC children from 2 to 8 years old. A total of 3862 maternal-child pairs were included in the analytic sample. The dependent variables was BMI trajectory category (decline, stable, steady gain and rapid gain); 325 (8.4%) children were classified as having a declining trajectory (BMI slope < - 0.05 kg/m²/month), 3037 (78.6%) children as having a stable trajectory (- 0.05 kg/m²/month ≤ BMI slope < 0.05 kg/m²/month), 308 (8.0%) children with a steady gain trajectory (0.05 kg/m²/month ≤ BMI slope < 0.10 kg/m²/month), and 192 (5.0%) children with a rapid gain trajectory (BMI slope > 0.10 kg/m²/month).

Table 4-12 presents the child BMI trajectory (outcome), maternal socio-demographic, pre-pregnancy, pregnancy, community characteristics and cohort characteristics for the study sample for Specific Aim 2. The sample characteristics for the 3862 maternal-child pairs included in the Specific Aim 2 analysis mimicked that for Specific Aim 1 with only minor differences in percentages for each independent variable. A total

of 25.5% of all women included in the analysis for Aim 2 had a pre-pregnancy BMI ≥ 30 kg/m², 35.0% of women resided in census-tracts characterized by extreme socioeconomic deprivation and 73.1% lived ≥ 0.5 miles from the nearest healthy food outlet.

Appendix A summarizes the cross-tabulation between maternal socio-demographic characteristics, maternal pre-pregnancy health, and pregnancy health and community characteristics by maternal pre-pregnancy BMI for the sample included in Specific Aim 2. Similar to Specific Aim 1, maternal pre-pregnancy BMI was statistically significantly associated with maternal race, marital status, educational attainment, insurance status, parity, age, chronic hypertension and diabetes, gestational diabetes, pregnancy associated hypertensive disorder and census-tract deprivation. In addition, child birth weight was associated with pre-pregnancy BMI in this sample as a 31.6% of all children < 1500 g and 32.0% of all children ≥ 4000 g were born to women with a BMI ≥ 30 kg/m² compared to 20.3% of children 1500 – 2499 g and 25.4% of children 2500 – 4000 grams.

Appendix B summarizes the cross-tabulation between maternal socio-demographic characteristics, maternal pre-pregnancy health, and pregnancy health and census-tract socioeconomic deprivation by neighborhood food environment for the sample included in Specific Aim 2. Like Specific Aim 1, neighborhood food environment was significantly associated with maternal race, marital status, educational attainment, insurance status, maternal age, smoking history, birth weight and census-tract deprivation.

Appendix C summarizes the cross-tabulation between maternal socio-demographic characteristics, maternal pre-pregnancy health, and pregnancy health and neighborhood food environment by census tract deprivation category for the sample included in Specific Aim 2. Similar

to Specific Aim 1, census-tract deprivation was associated with race, marital status, educational attainment, insurance status, maternal age, pre-pregnancy BMI, smoking history, pregnancy associated hypertensive disorder, birth weight and neighborhood food environment. Though parity was not associated with census-tract deprivation in the sample included in Aim 1, multiparous women were significantly more likely to reside in census-tracts characterized by minimal deprivation (16.1% versus 19.4%) and nulliparous women were statistically more likely to reside in census-tracts characterized by extreme deprivation (36.5% versus 32.2%). In addition, gestational diabetes was associated with census-tract deprivation for the sample included in Specific Aim 1, however, was not associated census-tract deprivation for the sample included in Specific Aim 2.

The same approach as for specific aim 1, Pearson's χ^2 Test of Independence, was used to evaluate the null hypothesis of no difference in child BMI trajectory category by levels of independent variables. Results are summarized in **Table 4-13**. Statistically significant associations were identified between child BMI trajectory category and maternal race, marital status, education, maternal pre-pregnancy BMI, diabetes mellitus, smoking history, gestational diabetes and census-tract deprivation. In addition, the child's birth year and duration of follow-up was significantly associated with BMI trajectory category. These cohort characteristics were adjusted for in all subsequent multivariable models. The percentage of children who fell into the decline, stable, steady gain and rapid gain BMI trajectories for children of women with pre-pregnancy BMI < 30 kg/m² as well as for women \geq 30 kg/m² were calculated (**Table 4-14**). Like Specific Aim 1, women with a BMI \geq 30 kg/m² had a higher percentage of children with a rapid gain trajectory at each level of census-tract deprivation. Women with a BMI

< 30 kg/m² who also had pre-gestational diabetes had a higher percentage of children with trajectories categorized by steady gain than their counterparts with diabetes and a pre-pregnancy BMI \geq 30 kg/m².

The strength of the association of each main predictor variables (maternal pre-pregnancy BMI, census-tract deprivation and food environment) and each statistically significant covariate with child BMI trajectory in χ^2 analysis was evaluated with simple multinomial logistic regression; results are presented in **Table 4-15**. All odds ratios were calculated with normal BMI trajectory ($-0.05 \text{ kg/m}^2 < \text{BMI} < 0.05 \text{ kg/m}^2$) as the reference group.

Maternal race/ethnicity, marital status and education were associated with childhood BMI trajectory in unadjusted models. Black/African-American race/ethnicity was associated with 83% increased odds of rapid gain, but not of decline or steady gain, when compared to White/Caucasian race/ethnicity. Children of married women had decreased odds of rapid gain when compared to children of unmarried women though no association was appreciated between marital status and decline or steady gain categories. Children of women who had any college also had decreased odds of rapid gain when compared to children of high school educated women; no additional association between education and BMI trajectory category was significant.

Maternal pre-pregnancy BMI, diabetes and smoking history were all associated with child BMI trajectory from 2 to 8 years. Maternal pre-pregnancy obesity was associated with 99% increased odds of steady gain and a 279% increased odds of rapid gain BMI trajectories. Children of women with pre-pregnancy diabetes had an almost 250% increased odds of rapid gain than children with mothers with the condition but did not differ for the decline or steady gain trajectories. Maternal smoking

history was associated with both increased odds of steady gain and of rapid gain but not of BMI decline.

Gestational diabetes was the only pregnancy health characteristics associated with BMI trajectory category. Children of women with gestational diabetes had 73% increased odds of a steady gain BMI trajectory and 83% increased odds of a rapid gain BMI trajectory than children of women without gestational diabetes; the decline group did not differ from the stable group.

Like specific aim 1, census-tract deprivation but not food environment was associated with BMI trajectory category. High census-tract deprivation was associated with steady gain and extreme census-tract deprivation was associated with rapid gain. No other quintile was associated with childhood BMI trajectory category from 2 to 8 years old.

A block-based sequential modeling approach was performed to assess potential confounding of the association between maternal pre-pregnancy BMI and childhood BMI trajectory category by sets of variables. The stable trajectory ($-0.05 \text{ kg/m}^2/\text{month} \leq \text{BMI slope} < 0.05 \text{ kg/m}^2/\text{month}$) was used as the reference category for all odds ratio calculations. Results of the sequential multivariable multinomial analyses are presented in **Tables 4-16, 4-17 and 4-18**. The full model results with all age groups of the dependent variable are shown in **Table 4-19**.

Table 4-16 presents the results of the sequential block-based regression for decline versus normal BMI trajectory children. The unadjusted OR for the relation between maternal pre-pregnancy BMI and the decline BMI trajectory category was 0.88 (95% CI: 0.67, 1.17) and thereby not statistically significant. The adjusted odds ratios after inclusion of community characteristics (Model 1) was 0.88, socio-demographic characteristics (Model 2) was 0.90, pre-pregnancy

characteristics (Model 3) was 0.90 and finally, pregnancy characteristics (Model 4) was 0.89.

Table 4-17 presents the results of sequential block-based regression for steady gain versus normal BMI trajectory children. The unadjusted OR for the relation between maternal pre-pregnancy BMI and steady gain BMI trajectory was 1.99 (95% CI: 1.56, 2.55). The aOR with the addition of community characteristics (Model 1) had a slight decrease to 1.94, likely a result of the positive confounding by the association between census-tract deprivation, maternal pre-pregnancy BMI and child BMI trajectory. The aOR was nearly identical with the addition of maternal socio-demographic characteristics (Model 2), pre-pregnancy health characteristics (Model 3) and pregnancy health characteristics (Model 4).

Table 4-18 presents the results of sequential block-based regression for rapid gain versus normal BMI trajectory children. The unadjusted OR for the relation between maternal pre-pregnancy BMI and steady gain BMI trajectory was 3.79 (95% CI: 2.82, 5.10). With the addition of community characteristics in Model 1, the aOR decreased to 3.67 likely reflecting some component of positive confounding between dyads who reside in extreme deprivation, maternal pre-pregnancy BMI and child BMI trajectory. The adjusted odds decreased only slightly with the addition of maternal socio-demographic characteristics in Model 2 (aOR: 3.65; 95% CI: 2.62, 5.09). After including maternal pre-pregnancy characteristics in the analysis (Model 3), there was another decrease in aOR to 3.54 (95% CI: 2.56, 4.90). This decrease was likely the result of positive confounding effect of pre-pregnancy diabetes, which after adjustment, weakened the strength of the association between maternal pre-pregnancy BMI and child BMI trajectory. The addition of

pregnancy health characteristics in Model 4 resulted with nearly identical aOR to Model 3.

Table 4-19 presents the final multivariable multinomial regression model with all three trajectory groups adjusted for maternal pre-pregnancy BMI, census-tract deprivation, neighborhood food environment and all additional maternal socio-demographic, pre-pregnancy health, pregnancy health and community characteristics found to be significant in unadjusted models. The model explaining the most variance between the independent variables and child BMI trajectory included all significant maternal socio-demographic, pre-pregnancy health, pregnancy health and community characteristics significant in simple regression.

In adjusted models, maternal Hispanic race/ethnicity was the only race/ethnicity category associated with BMI trajectory from 2 to 8 years old. Children of Hispanic women had 86% higher odds of decline and 65% higher odds of steady gain than children of White/Caucasian mothers. Hispanic race/ethnicity was not associated with rapid gain trajectory. Marital status was associated with rapid gain such that children of married women had 53% decreased odds of rapid gain than those of unmarried women. Marital status was not associated with decline or steady gain trajectories.

Children of mothers with pre-pregnancy obesity had 85% greater odds of steady gain and 249% greater odds of rapid gain BMI trajectories, but did not differ from children with stable trajectories from the BMI decline trajectory group. Both a history of smoking and gestational diabetes were associated with an increased odds of steady gain trajectory though not of decline or rapid gain trajectory. Neither census-tract deprivation nor community food environment were associated with BMI trajectory category from 2 to 8 years old.

In summary, Specific Aim 1 investigated the association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with BMI of children at 5-years old. Maternal pre-pregnancy BMI ≥ 30 kg/m² was strongly associated with childhood overweight and obesity at 5-years and children who resided in communities characterized by extreme socio-economic deprivation had a significantly higher odds of obesity compared to their counterparts in less deprived communities. Specific Aim 2 evaluated the association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment with child BMI trajectories from 2 to 8 years old, evaluating the impact of mother pre-pregnancy weight status and neighborhood characteristics on a longitudinal outcome. Like specific aim 1, maternal pre-pregnancy BMI was strongly associated with child steady gain and rapid gain BMI trajectories, however, neither census-tract socio-economic deprivation nor neighborhood food environment were associated with child BMI trajectory.

Maternal pre-pregnancy BMI and neighborhood characteristics

While it is possible that variables such as local food environment and neighborhood deprivation have an effect on child weight status, it is more likely that these environmental characteristics impact both maternal and child weight status given the shared nature of these exposures. In addition, it is possible that associations between maternal and child BMI are partially confounded by neighborhood characteristics. In order to examine these relations, supplemental analyses were performed to evaluate the association between neighborhood characteristics and maternal pre-pregnancy BMI.

A total of 4770 women were included in this analysis, representing 98% of the complete DMBC. **Table 4-20** describes the sample

characteristics. Most subjects self-identified as non-Hispanic white (39.3%) or black/African-American (45.7%), were single, widowed or divorced (56.3%), at least high school educated (76.2%), publicly insured (55.5%), multiparous (64.8%) and between age 18 and 34 at the time of delivery (83.4%). Only a small percentage of the sample had a pre-pregnancy diagnosis of chronic hypertension (3.9%) or diabetes mellitus (1.2%) and over one in five women report ever smoking (20.5%). The percentage of the sample who resided in census-tracts with minimal, mild, moderate and high levels of deprivation was similar (15.3% - 18.1%), however, over one-third of the sample (34.3%) of women lived in tracts with extreme deprivation.

Almost one-third of Black/African-American women were obese (31.8%) and had the highest average pre-pregnancy BMI (28.0 kg/m^2) of any racial/ethnic group. Marital status, parity, age, educational achievement, and insurance status were associated with maternal pre-pregnancy BMI category. Single, widowed and divorced women had a higher mean BMI than their married counterparts (27.1 versus 26.3 kg/m^2). Similarly, 3 in 10 high school educated women were obese compared to just over 20% of women who did not graduate from high school (22.8%) and women who had any college education (22.5%). Privately insured women were less likely to be obese (22.5%) than those with public insurance (27.8%). A greater percentage of multiparous women (28.1%) and women older than 35 (28.4%) were obese than their respective comparisons.

A significantly higher percentage of women with chronic hypertension (58.5%) and diabetes mellitus (52.6%) had a BMI $\geq 30 \text{ kg/m}^2$ than those without chronic hypertension (24.1%) or pre-pregnancy diabetes (25.1%). A history of smoking was also associated with higher maternal mean BMI; almost 30% of women with any smoking history had a

BMI ≥ 30 kg/m². There was a direct association between neighborhood socio-economic deprivation and maternal obesity. Women residing in neighborhood characterized by minimal socio-economic deprivation had BMI values almost 3 kg/m² less on average than their counterparts in neighborhoods characterized by extreme deprivation (24.9 kg/m² versus 27.7 kg/m²).

Statistical testing of the association between maternal pre-pregnancy BMI and each socio-demographic, pre-pregnancy and community characteristic was performed with χ^2 as maternal BMI was operationalized as a categorical variable (**Table 4-20**). Maternal race, marital status, education, insurance, parity, age, chronic hypertension, diabetes mellitus, smoking history and census-tract deprivation were significantly associated with maternal pre-pregnancy BMI. Logistic regression was performed to calculate unadjusted odds ratios associated with maternal obesity (**Table 4-21**).

A decreased odd of maternal obesity was noted among women of Asian race/ethnicity, with less than high school or any college education and age < 18. Black/African-American women (aOR: 1.85; 95% CI: 1.60, 2.13), and women on public insurance (aOR: 1.32; 95% CI: 1.16, 1.51), with chronic hypertension (aOR 4.44; 95% CI: 3.30, 5.99), with diabetes mellitus (aOR 3.31; 95% CI: 1.96, 5.59) and who reported smoking (aOR: 1.28; 95% CI: 1.07, 1.46) had increased odds of maternal obesity. In addition, there was a direct association between increased census-tract socioeconomic deprivation and maternal obesity such that the odds of obesity in women residing in census tracts characterized by extreme deprivation was 2.5 times that of women residing in neighborhoods characterized by minimal deprivation.

Multivariable logistic regression was performed to evaluate the association between neighborhood characteristics and maternal pre-

pregnancy BMI after adjusting for maternal socio-demographic and pre-pregnancy health characteristics known to be associated with maternal weight status (**Table 4-22**). Black/African-American women (aOR: 1.58; 95% CI: 1.32, 1.89), and women with chronic hypertension (aOR: 3.60; 95% CI: 2.64, 4.65) and diabetes mellitus (aOR: 2.65; 95% CI: 1.51, 4.65) had increased odds of maternal obesity. There was an association between neighborhood census-tract deprivation and maternal obesity such that women residing in neighborhoods characterized by extreme (aOR: 1.88; 95% CI: 1.44, 2.46), high (aOR: 1.92; 95% CI: 1.46, 2.54), moderate (aOR: 1.96; 95% CI: 1.51, 2.54) and mild (aOR: 1.68; 95% CI: 1.28, 2.19) deprivation had a higher odds of maternal obesity than those residing in neighborhoods with minimal deprivation. Maternal of Asian race had decreased odds of maternal obesity as did women with less than high school or more than college education when compared to their high-school educated counterparts. In addition, nulliparous women were found to have a lower BMI than women who had previous pregnancies. Age < 18 was also found to be associated with a decreased odds of maternal pre-pregnancy obesity.

Table 4-1: Maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics of the study sample, aim 1 (n = 3101)

| Variable | N (%) |
|---|-------------|
| Child body mass index (BMI) percentile | |
| <5 th | 95 (3.1) |
| 5 - 84.9 th | 2051 (66.1) |
| 85 - 94.9 th | 542 (17.5) |
| ≥ 95 th | 413 (13.3) |
| Maternal socio-demographic characteristics | |
| Race/Ethnicity | |
| Caucasian/White | 1241 (40.0) |
| Black/African-American | 1421 (45.8) |
| Hispanic, non-Caucasian | 346 (11.2) |
| Asian | 64 (2.0) |
| Other | 29 (1.0) |
| Marital status | |
| Single, widowed, divorced | 1701 (54.8) |
| Married | 1400 (45.2) |
| Education | |
| Less than high school | 714 (23.0) |
| High school graduate | 1090 (35.2) |
| Any college | 1297 (41.8) |
| Insurance | |
| Private | 1453 (46.9) |
| Public | 1648 (53.1) |
| Parity | |
| Nulliparous | 1082 (34.9) |
| Multiparous | 2019 (65.1) |
| Age (years) | |
| < 18 | 153 (4.9) |
| 18 - 34 | 2561 (82.6) |
| ≥ 35 | 387 (14.5) |
| Maternal pre-pregnancy health characteristics | |
| Pre-pregnancy BMI | |
| < 30 kg/m ² | 2304 (74.3) |
| ≥ 30 kg/m ² | 797 (25.7) |
| Chronic hypertension | |
| No | 2983 (96.2) |
| Yes | 118 (3.8) |
| Diabetes mellitus | |
| No | 3071 (99.0) |
| Yes | 30 (1.0) |
| Smoking history | |
| No | 2464 (79.5) |
| Yes | 637 (20.5) |
| Pregnancy health characteristics | |
| Gestational diabetes | |
| No | 2900 (93.5) |
| Yes | 201 (6.5) |
| Pregnancy hypertensive disorder | |
| No | 2876 (92.7) |
| Yes | 225 (7.3) |
| Birth weight (g) | |
| < 1500 | 47 (1.5) |
| 1500 - 2499 | 237 (7.7) |
| 2500 - 3999 | 2605 (84.0) |
| ≥ 4000 | 212 (6.8) |

| | |
|-------------------------------|-------------|
| Community characteristics | |
| Census-tract deprivation | |
| Minimal | 562 (18.1) |
| Mild | 459 (14.8) |
| Moderate | 563 (18.2) |
| High | 448 (14.4) |
| Extreme | 1069 (34.5) |
| Neighborhood food environment | |
| < 0.5 miles | 795 (25.6) |
| ≥ 0.5 miles | 2306 (74.4) |

Table 4-2: Maternal pre-pregnancy body mass index (BMI) by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 1 (n = 3101)

| Variable | N (%) | | | p |
|---|--------------|------------------------|------------------------|--------|
| | All | < 30 kg/m ² | ≥ 30 kg/m ² | |
| Maternal socio-demographic characteristics | | | | |
| Race | | | | |
| Caucasian/White | 1241 (40.02) | 1000 (80.58) | 241 (19.42) | <0.001 |
| Black/African-American | 1421 (45.82) | 962 (67.70) | 459 (32.30) | |
| Hispanic, non-Caucasian | 346 (11.16) | 262 (75.72) | 84 (24.28) | |
| Asian | 64 (2.06) | 59 (92.19) | 5 (7.81) | |
| Other | 29 (0.94) | 21 (72.41) | 8 (27.59) | |
| Marital status | | | | |
| Single, widowed, divorced | 1701 (54.85) | 1201 (70.61) | 500 (29.63) | <0.001 |
| Married | 1400 (45.15) | 1103 (78.79) | 297 (21.21) | |
| Education | | | | |
| Less than high school | 714 (23.02) | 550 (77.03) | 164 (22.97) | <0.001 |
| High school graduate | 1090 (35.15) | 739 (67.80) | 351 (32.20) | |
| Any college | 1297 (41.83) | 1015 (78.26) | 282 (21.74) | |
| Insurance | | | | |
| Private | 1453 (46.86) | 1136 (78.18) | 317 (21.82) | <0.001 |
| Public | 1648 (53.14) | 1168 (70.87) | 480 (29.13) | |
| Parity | | | | |
| Nulliparous | 1082 (34.89) | 851 (78.65) | 231 (21.35) | <0.001 |
| Multiparous | 2019 (65.11) | 1453 (71.97) | 566 (28.03) | |
| Age (years) | | | | |
| < 18 | 153 (4.93) | 140 (91.50) | 13 (8.50) | <0.001 |
| 18 - 34 | 2561 (82.59) | 1890 (73.80) | 671 (26.20) | |
| ≥ 35 | 387 (14.48) | 274 (70.80) | 113 (29.20) | |
| Maternal pre-pregnancy health characteristics | | | | |
| Chronic hypertension | | | | |
| No | 2983 (96.19) | 2252 (75.49) | 731 (24.51) | <0.001 |
| Yes | 118 (3.81) | 52 (44.07) | 66 (55.93) | |
| Diabetes mellitus | | | | |
| No | 3071 (99.03) | 2290 (74.57) | 781 (25.43) | <0.001 |
| Yes | 30 (0.97) | 14 (46.67) | 16 (53.33) | |
| Smoking history | | | | |
| No | 2464 (79.46) | 1845 (74.88) | 619 (25.12) | 0.146 |
| Yes | 637 (20.54) | 459 (72.06) | 178 (27.94) | |
| Pregnancy health characteristics | | | | |
| Gestational diabetes | | | | |
| No | 2900 (93.52) | 2205 (76.03) | 695 (23.97) | <0.001 |
| Yes | 201 (6.48) | 99 (49.25) | 102 (50.75) | |
| Pregnancy hypertensive disorder | | | | |
| No | 2876 (92.74) | 2165 (75.28) | 711 (24.72) | <0.001 |
| Yes | 225 (7.26) | 139 (61.78) | 86 (38.22) | |
| Birth weight (g) | | | | |
| < 1500 | 47 (1.52) | 32 (68.09) | 15 (31.91) | 0.097 |
| 1500 - 2499 | 237 (7.64) | 187 (78.90) | 50 (21.10) | |
| 2500 - 3999 | 2605 (84.01) | 1938 (74.40) | 667 (25.60) | |
| ≥ 4000 | 212 (6.84) | 147 (69.34) | 65 (30.66) | |
| Community characteristics | | | | |
| Census-tract deprivation | | | | |
| Minimal | 562 (18.12) | 489 (87.01) | 73 (12.99) | <0.001 |
| Mild | 459 (14.80) | 365 (77.56) | 103 (22.44) | |
| Moderate | 563 (18.16) | 407 (72.29) | 156 (27.71) | |
| High | 448 (14.45) | 310 (69.20) | 138 (30.80) | |
| Extreme | 1069 (34.47) | 742 (69.41) | 327 (30.59) | |
| Neighborhood food environment | | | | |
| < 0.5 miles | 795 (25.64) | 1728 (74.93) | 578 (25.07) | <0.001 |
| ≥ 0.5 miles | 2306 (74.36) | 576 (72.45) | 219 (27.55) | |

Table 4-3: Neighborhood food environment by maternal socio-demographic, pre-pregnancy health, pregnancy health and census-tract deprivation, aim 1 (n = 3101)

| Variable | N (%) | | | p |
|---|--------------|-------------|--------------|--------|
| | All | < 0.5 miles | ≥ 0.5 miles | |
| Maternal socio-demographic characteristics | | | | |
| Race | | | | |
| Caucasian/White | 1241 (40.02) | 195 (15.71) | 1046 (84.29) | <0.001 |
| Black/African-American | 1421 (45.82) | 493 (34.69) | 928 (65.31) | |
| Hispanic, non-Caucasian | 346 (11.16) | 90 (26.01) | 256 (73.99) | |
| Asian | 64 (2.06) | 10 (15.63) | 54 (84.38) | |
| Other | 29 (0.94) | 7 (24.14) | 22 (75.86) | |
| Marital status | | | | |
| Single, widowed, divorced | 1701 (54.85) | 580 (34.10) | 1121 (65.90) | <0.001 |
| Married | 1400 (45.15) | 215 (15.36) | 1185 (84.64) | |
| Education | | | | |
| Less than high school | 714 (23.02) | 226 (31.65) | 488 (68.35) | <0.001 |
| High school graduate | 1090 (35.15) | 324 (29.72) | 766 (70.28) | |
| Any college | 1297 (41.83) | 245 (18.89) | 1052 (81.11) | |
| Insurance | | | | |
| Private | 1453 (46.86) | 244 (16.79) | 1209 (83.21) | <0.001 |
| Public | 1648 (53.14) | 551 (33.43) | 1097 (66.57) | |
| Parity | | | | |
| Nulliparous | 1082 (34.89) | 517 (25.61) | 1502 (74.39) | 0.958 |
| Multiparous | 2019 (65.11) | 278 (25.69) | 804 (74.31) | |
| Age (years) | | | | |
| < 18 | 153 (4.93) | 53 (34.64) | 100 (65.36) | <0.001 |
| 18 – 34 | 2561 (82.59) | 671 (26.20) | 1890 (73.80) | |
| ≥ 35 | 387 (14.48) | 71 (18.35) | 316 (81.65) | |
| Maternal pre-pregnancy health characteristics | | | | |
| Pre-pregnancy BMI | | | | |
| < 30 kg/m ² | 2304 (74.30) | 576 (25.00) | 1728 (75.00) | 0.167 |
| ≥ 30 kg/m ² | 797 (25.70) | 219 (27.48) | 578 (72.52) | |
| Chronic hypertension | | | | |
| No | 2983 (96.19) | 768 (25.75) | 2215 (74.25) | 0.485 |
| Yes | 118 (3.81) | 27 (22.88) | 91 (77.12) | |
| Diabetes mellitus | | | | |
| No | 3071 (99.03) | 788 (25.66) | 2283 (74.34) | 0.772 |
| Yes | 30 (0.97) | 7 (23.33) | 23 (76.67) | |
| Smoking history | | | | |
| No | 2464 (79.46) | 601 (24.39) | 1863 (75.61) | <0.001 |
| Yes | 637 (20.54) | 194 (30.46) | 443 (69.54) | |
| Pregnancy health characteristics | | | | |
| Gestational diabetes | | | | |
| No | 2900 (93.52) | 753 (25.97) | 2147 (74.03) | 0.111 |
| Yes | 201 (6.48) | 42 (20.90) | 159 (79.10) | |
| Pregnancy hypertensive disorder | | | | |
| No | 2876 (92.74) | 733 (25.49) | 2143 (74.51) | 0.494 |
| Yes | 225 (7.26) | 62 (27.56) | 163 (72.44) | |
| Birth weight (g) | | | | |
| < 1500 | 47 (1.52) | 23 (48.94) | 24 (51.06) | <0.001 |
| 1500 – 2499 | 237 (7.64) | 70 (29.54) | 167 (70.46) | |
| 2500 – 3999 | 2605 (84.01) | 658 (25.26) | 1947 (74.74) | |
| ≥ 4000 | 212 (6.84) | 44 (20.75) | 168 (79.25) | |
| Community characteristics | | | | |
| Census-tract deprivation | | | | |
| Minimal | 562 (18.12) | 90 (16.01) | 472 (83.99) | <0.001 |
| Mild | 459 (14.80) | 57 (12.42) | 402 (87.58) | |
| Moderate | 563 (18.16) | 136 (24.16) | 427 (75.84) | |
| High | 448 (14.45) | 29 (6.47) | 419 (93.53) | |
| Extreme | 1069 (34.47) | 483 (45.18) | 586 (54.82) | |

Table 4-4: Census-tract deprivation by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood food environment, aim 1 (n = 3101)

| Variable | N (%) | | | | | | p |
|---|--------------|-------------|-------------|-------------|-------------|--------------|--------|
| | All | Minimal | Mild | Moderate | High | Extreme | |
| Maternal socio-demographic characteristics | | | | | | | |
| Race | | | | | | | |
| Caucasian/White | 1241 (40.02) | 430 (34.65) | 289 (23.29) | 268 (21.60) | 136 (10.96) | 118 (9.51) | <0.001 |
| Black/African-American | 1421 (45.82) | 76 (5.35) | 120 (8.44) | 219 (15.41) | 206 (14.50) | 800 (56.30) | |
| Hispanic, non-Caucasian | 346 (11.16) | 23 (6.65) | 35 (10.12) | 56 (16.18) | 93 (26.88) | 139 (40.17) | |
| Asian | 64 (2.06) | 28 (43.75) | 13 (20.31) | 12 (18.75) | 5 (7.81) | 6 (9.38) | |
| Other | 29 (0.94) | 5 (17.24) | 2 (6.90) | 8 (27.59) | 8 (27.59) | 6 (20.69) | |
| Marital status | | | | | | | |
| Single, widowed, divorced | 1701 (54.85) | 94 (5.53) | 164 (9.64) | 269 (15.81) | 301 (17.70) | 873 (51.32) | <0.001 |
| Married | 1400 (45.15) | 468 (33.43) | 295 (21.07) | 294 (21.00) | 147 (10.50) | 196 (14.00) | |
| Education | | | | | | | |
| Less than high school | 714 (23.02) | 27 (3.78) | 54 (7.56) | 105 (14.71) | 130 (18.21) | 398 (55.74) | <0.001 |
| High school graduate | 1090 (35.15) | 99 (9.08) | 149 (13.67) | 201 (18.44) | 180 (16.51) | 461 (42.29) | |
| Any college | 1297 (41.83) | 436 (33.62) | 256 (19.74) | 257 (19.81) | 138 (10.64) | 210 (16.19) | |
| Insurance | | | | | | | |
| Private | 1453 (46.86) | 458 (31.52) | 307 (21.13) | 315 (21.68) | 151 (10.39) | 222 (15.28) | <0.001 |
| Public | 1648 (53.14) | 104 (6.31) | 152 (9.22) | 248 (15.05) | 297 (18.02) | 847 (51.40) | |
| Parity | | | | | | | |
| Nulliparous | 1082 (34.89) | 218 (20.15) | 171 (15.80) | 193 (17.84) | 156 (14.42) | 344 (31.79) | 0.077 |
| Multiparous | 2019 (65.11) | 344 (17.04) | 288 (14.26) | 370 (18.33) | 292 (14.46) | 725 (35.91) | |
| Age (years) | | | | | | | |
| < 18 | 153 (4.93) | 4 (2.61) | 12 (7.84) | 19 (12.42) | 23 (15.03) | 95 (62.09) | <0.001 |
| 18 - 34 | 2561 (82.59) | 429 (16.75) | 367 (14.33) | 472 (18.43) | 380 (14.84) | 913 (35.65) | |
| ≥ 35 | 387 (14.48) | 129 (33.33) | 80 (20.67) | 72 (18.60) | 45 (11.63) | 61 (15.76) | |
| Maternal pre-pregnancy health characteristics | | | | | | | |
| Pre-pregnancy BMI | | | | | | | |
| < 30 kg/m ² | 2304 (74.30) | 489 (21.22) | 356 (15.45) | 407 (17.66) | 310 (13.45) | 742 (32.20) | <0.001 |
| ≥ 30 kg/m ² | 797 (25.70) | 73 (9.16) | 103 (12.92) | 156 (19.57) | 138 (17.31) | 327 (41.03) | |
| Chronic hypertension | | | | | | | |
| No | 2983 (96.19) | 548 (18.37) | 439 (14.72) | 540 (18.10) | 427 (14.31) | 1029 (34.50) | 0.390 |
| Yes | 118 (3.81) | 14 (11.86) | 20 (16.95) | 23 (19.49) | 21 (17.80) | 40 (33.90) | |
| Diabetes mellitus | | | | | | | |
| No | 3071 (99.03) | 558 (18.17) | 454 (14.78) | 553 (18.01) | 443 (14.43) | 1063 (34.61) | 0.182 |
| Yes | 30 (0.97) | 4 (13.33) | 5 (16.67) | 10 (33.33) | 5 (16.67) | 6 (20.00) | |

| | | | | | | | |
|----------------------------------|--------------|-------------|-------------|-------------|-------------|--------------|--------|
| Smoking history | | | | | | | |
| No | 2464 (79.46) | 500 (20.29) | 383 (15.54) | 455 (18.47) | 338 (13.72) | 788 (31.98) | <0.001 |
| Yes | 637 (20.54) | 62 (9.73) | 76 (11.93) | 108 (16.95) | 110 (17.27) | 281 (44.11) | |
| Pregnancy health characteristics | | | | | | | |
| Gestational diabetes | | | | | | | |
| No | 2900 (93.52) | 530 (18.28) | 430 (14.83) | 525 (18.10) | 405 (13.97) | 1010 (34.83) | 0.050 |
| Yes | 201 (6.48) | 32 (15.92) | 29 (14.43) | 38 (18.91) | 43 (21.39) | 59 (29.35) | |
| Pregnancy hypertensive disorder | | | | | | | |
| No | 2876 (92.74) | 538 (18.71) | 418 (14.53) | 520 (18.08) | 407 (14.15) | 993 (34.53) | 0.018 |
| Yes | 225 (7.26) | 24 (10.67) | 41 (18.22) | 43 (19.11) | 41 (18.22) | 76 (33.78) | |
| Birth weight (g) | | | | | | | |
| < 1500 | 47 (1.52) | 3 (6.38) | 5 (10.64) | 10 (21.28) | 9 (19.15) | 20 (42.55) | <0.001 |
| 1500 - 2499 | 237 (7.64) | 23 (9.70) | 23 (9.70) | 49 (20.68) | 44 (18.57) | 98 (41.35) | |
| 2500 - 3999 | 2605 (84.01) | 487 (18.69) | 390 (14.97) | 457 (17.54) | 358 (13.74) | 913 (32.05) | |
| ≥ 4000 | 212 (6.84) | 49 (23.11) | 41 (19.34) | 47 (22.17) | 37 (17.45) | 38 (17.92) | |
| Community characteristics | | | | | | | |
| Neighborhood food environment | | | | | | | |
| < 0.5 miles | 795 (25.64) | 90 (11.32) | 57 (7.17) | 136 (17.11) | 29 (3.65) | 483 (60.75) | <0.001 |
| ≥ 0.5 miles | 2306 (74.36) | 472 (20.47) | 402 (17.43) | 427 (18.52) | 419 (18.17) | 586 (25.41) | |

Table 4-5: Child BMI percentile at 5 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 1 (n = 3101)

| Variable | N (%) | | | | | P |
|---|--------------|-------------|---------------|-------------|-------------|--------|
| | All | Underweight | Normal weight | Overweight | Obese | |
| Maternal socio-demographic characteristics | | | | | | <0.001 |
| Race | | | | | | |
| Caucasian/White | 1241 (40.02) | 35 (2.82) | 858 (69.14) | 219 (17.65) | 129 (10.39) | |
| Black/African-American | 1421 (45.82) | 44 (3.10) | 926 (65.17) | 251 (17.66) | 200 (14.07) | |
| Hispanic, non-Caucasian | 346 (11.16) | 7 (2.02) | 204 (58.96) | 60 (17.34) | 75 (21.68) | |
| Asian | 64 (2.06) | 7 (10.94) | 42 (65.63) | 9 (14.06) | 6 (9.38) | |
| Other | 29 (0.94) | 2 (6.90) | 21 (72.41) | 3 (10.34) | 3 (10.34) | |
| Marital status | | | | | | 0.002 |
| Single, widowed, divorced | 1701 (54.85) | 45 (2.65) | 1091 (64.14) | 306 (17.99) | 259 (15.23) | |
| Married | 1400 (45.15) | 50 (3.57) | 960 (68.57) | 236 (16.86) | 154 (11.00) | |
| Education | | | | | | 0.003 |
| Less than high school | 714 (23.02) | 24 (3.36) | 447 (62.61) | 126 (17.65) | 117 (16.39) | |
| High school graduate | 1090 (35.15) | 24 (2.20) | 703 (64.50) | 204 (18.72) | 156 (14.50) | |
| Any college | 1297 (41.83) | 47 (3.62) | 901 (69.47) | 212 (16.35) | 137 (10.56) | |
| Insurance | | | | | | 0.002 |
| Private | 1453 (46.86) | 52 (3.58) | 991 (68.20) | 249 (17.14) | 161 (11.08) | |
| Public | 1648 (53.14) | 43 (2.61) | 1060 (64.32) | 293 (17.78) | 252 (15.29) | |
| Parity | | | | | | 0.022 |
| Nulliparous | 1082 (34.89) | 53 (2.63) | 1371 (67.90) | 338 (16.74) | 257 (12.73) | |
| Multiparous | 2019 (65.11) | 42 (3.88) | 680 (62.85) | 204 (10.85) | 156 (14.42) | |
| Age (years) | | | | | | 0.682 |
| < 18 | 153 (4.93) | 4 (2.61) | 101 (66.01) | 23 (15.03) | 25 (16.34) | |
| 18 - 34 | 2561 (82.59) | 80 (3.12) | 1699 (66.34) | 441 (17.22) | 341 (13.32) | |
| ≥ 35 | 387 (14.48) | 11 (2.84) | 251 (64.86) | 78 (20.16) | 47 (12.14) | |
| Maternal pre-pregnancy health characteristics | | | | | | <0.001 |
| Pre-pregnancy BMI | | | | | | |
| < 30 kg/m ² | 2304 (74.30) | 79 (3.43) | 1643 (71.31) | 360 (15.63) | 222 (9.64) | |
| ≥ 30 kg/m ² | 797 (25.70) | 16 (2.01) | 408 (51.19) | 182 (22.84) | 191 (23.96) | |
| Chronic hypertension | | | | | | 0.244 |
| No | 2983 (96.19) | 89 (2.98) | 1980 (66.38) | 522 (17.50) | 392 (13.14) | |
| Yes | 118 (3.81) | 6 (5.08) | 71 (60.17) | 20 (16.95) | 21 (17.80) | |
| Diabetes mellitus | | | | | | 0.722 |
| No | 3071 (99.03) | 95 (3.05) | 2032 (66.17) | 536 (17.45) | 408 (13.29) | |
| Yes | 30 (0.97) | 0 (0.00) | 19 (63.33) | 6 (20.00) | 5 (16.67) | |

| | | | | | | |
|----------------------------------|--------------|-----------|--------------|-------------|-------------|--------|
| Smoking history | | | | | | |
| No | 2464 (79.46) | 78 (3.17) | 1636 (66.40) | 424 (17.21) | 326 (13.23) | 0.778 |
| Yes | 637 (20.54) | 17 (2.67) | 415 (65.15) | 118 (18.52) | 87 (13.66) | |
| Pregnancy health characteristics | | | | | | |
| Gestational diabetes | | | | | | |
| No | 2900 (93.52) | 92 (3.17) | 1932 (66.62) | 505 (17.41) | 371 (12.79) | 0.005 |
| Yes | 201 (6.48) | 3 (1.42) | 119 (59.20) | 37 (18.41) | 42 (30.90) | |
| Pregnancy hypertensive disorder | | | | | | |
| No | 2876 (92.74) | 89 (3.09) | 1906 (66.27) | 496 (17.25) | 385 (13.39) | 0.662 |
| Yes | 225 (7.26) | 6 (2.67) | 145 (64.44) | 46 (20.44) | 28 (12.44) | |
| Birth weight (g) | | | | | | |
| < 1500 | 47 (1.52) | 3 (6.38) | 27 (57.45) | 10 (21.28) | 7 (14.89) | 0.039 |
| 1500 - 2499 | 237 (7.64) | 10 (4.22) | 173 (73.00) | 32 (13.50) | 22 (9.28) | |
| 2500 - 3999 | 2605 (84.01) | 80 (3.07) | 1721 (66.07) | 455 (17.47) | 349 (13.40) | |
| ≥ 4000 | 212 (6.84) | 2 (0.94) | 130 (61.32) | 45 (21.23) | 35 (16.51) | |
| Community characteristics | | | | | | |
| Census-tract deprivation | | | | | | |
| Minimal | 562 (18.12) | 22 (3.91) | 398 (70.82) | 97 (17.26) | 45 (8.01) | <0.001 |
| Mild | 459 (14.80) | 19 (4.14) | 311 (67.76) | 74 (16.12) | 55 (11.98) | |
| Moderate | 563 (18.16) | 13 (2.31) | 386 (68.56) | 104 (18.47) | 60 (10.66) | |
| High | 448 (14.45) | 13 (2.90) | 279 (62.28) | 83 (18.53) | 73 (16.29) | |
| Extreme | 1069 (34.47) | 28 (2.62) | 677 (63.33) | 184 (17.21) | 180 (16.84) | |
| Neighborhood food environment | | | | | | |
| < 0.5 miles | 795 (25.64) | 21 (2.64) | 532 (66.92) | 134 (16.86) | 108 (13.58) | 0.798 |
| ≥ 0.5 miles | 2306 (74.36) | 74 (3.21) | 1519 (65.87) | 408 (17.69) | 305 (12.23) | |

Table 4-6: Pre-pregnancy BMI-specific percentages of underweight, normal weight, overweight and obese at 5-years for children in the Delaware Mother and Baby Cohort (DMBC)

| Variable | (%) | | | | | | | |
|---|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| | Underweight | | Normal Weight | | Overweight | | Obese | |
| | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² |
| Maternal socio-demographic characteristics | | | | | | | | |
| Race | | | | | | | | |
| Caucasian/White | 3.0 | 2.1 | 73.9 | 49.4 | 16.6 | 22.0 | 6.5 | 26.6 |
| Black/African-American | 3.5 | 2.2 | 71.3 | 52.3 | 14.9 | 23.5 | 10.3 | 22.0 |
| Hispanic, non-Caucasian | 2.3 | 1.2 | 61.8 | 50.0 | 16.4 | 20.2 | 19.5 | 28.6 |
| Asian | 11.9 | - | 66.1 | 60.0 | 11.9 | 40.0 | 10.2 | - |
| Other | 9.5 | - | 80.9 | 50.0 | 4.8 | 25.0 | 4.8 | - |
| Marital status | | | | | | | | |
| Single, widowed, divorced | 3.0 | 1.8 | 69.2 | 51.8 | 16.4 | 21.8 | 11.3 | 24.6 |
| Married | 3.9 | 2.4 | 73.5 | 50.2 | 14.8 | 24.6 | 7.8 | 22.9 |
| Education | | | | | | | | |
| Less than high school | 4.0 | 1.2 | 65.8 | 51.8 | 16.2 | 22.6 | 14.0 | 24.4 |
| High school graduate | 2.6 | 1.4 | 70.1 | 52.7 | 16.5 | 23.4 | 10.8 | 22.5 |
| Any college | 3.7 | 3.2 | 75.2 | 48.9 | 14.7 | 22.3 | 6.4 | 25.5 |
| Insurance | | | | | | | | |
| Private | 4.0 | 2.2 | 74.0 | 47.3 | 14.9 | 25.2 | 7.1 | 25.2 |
| Public | 2.9 | 1.9 | 68.7 | 53.8 | 16.4 | 21.3 | 12.1 | 23.1 |
| Parity | | | | | | | | |
| Nulliparous | 2.9 | 2.2 | 72.6 | 40.7 | 15.1 | 27.7 | 9.2 | 29.4 |
| Multiparous | 4.4 | 1.9 | 68.9 | 55.5 | 16.5 | 20.9 | 10.3 | 21.8 |
| Age (years) | | | | | | | | |
| < 18 | 3.5 | - | 71.1 | 23.1 | 15.0 | 15.4 | 12.2 | 61.5 |
| 18 - 34 | 2.9 | 1.9 | 70.0 | 52.9 | 15.5 | 22.1 | 9.8 | 23.1 |
| ≥ 35 | 2.9 | 2.7 | 73.4 | 44.3 | 16.8 | 28.3 | 6.9 | 24.8 |
| Maternal pre-pregnancy health characteristics | | | | | | | | |
| Chronic hypertension | | | | | | | | |
| No | 3.4 | 1.8 | 71.4 | 51.0 | 15.6 | 23.4 | 9.7 | 23.8 |
| Yes | 5.7 | 4.6 | 69.2 | 53.0 | 17.3 | 16.7 | 7.8 | 25.8 |
| Diabetes mellitus | | | | | | | | |
| No | 3.4 | 2.1 | 71.2 | 51.4 | 15.6 | 22.8 | 9.7 | 23.8 |
| Yes | - | - | 85.7 | 43.8 | 14.3 | 25.0 | - | 31.3 |
| Smoking history | | | | | | | | |
| No | 3.6 | 1.9 | 71.9 | 49.9 | 15.5 | 22.5 | 9.1 | 25.7 |
| Yes | 2.8 | 2.3 | 68.9 | 55.6 | 16.3 | 24.2 | 11.9 | 18.0 |

| | | | | | | | | |
|----------------------------------|-----|-----|------|------|------|------|------|------|
| Pregnancy health characteristics | | | | | | | | |
| Gestational diabetes | | | | | | | | |
| No | 3.5 | 2.0 | 71.3 | 52.1 | 15.5 | 22.7 | 9.7 | 23.2 |
| Yes | 1.0 | 2.0 | 71.2 | 45.1 | 17.3 | 23.5 | 8.6 | 29.4 |
| Pregnancy hypertensive disorder | | | | | | | | |
| No | 3.5 | 2.0 | 71.2 | 50.9 | 15.7 | 22.5 | 9.5 | 24.6 |
| Yes | 2.9 | 2.3 | 73.7 | 53.5 | 13.1 | 25.6 | 12.1 | 18.6 |
| Birth weight (g) | | | | | | | | |
| < 1500 | 9.4 | - | 59.4 | 53.3 | 21.9 | 20.0 | 9.4 | 26.7 |
| 1500 - 2499 | 3.2 | 8.0 | 79.2 | 50.0 | 11.2 | 22.0 | 6.4 | 20.0 |
| 2500 - 3999 | 3.5 | 1.8 | 71.2 | 51.3 | 15.4 | 23.4 | 9.9 | 23.5 |
| ≥ 4000 | 1.4 | 2.0 | 66.0 | 51.2 | 22.5 | 22.8 | 10.2 | 24.0 |
| Community characteristics | | | | | | | | |
| Census-tract deprivation | | | | | | | | |
| Minimal | 3.6 | 5.5 | 74.6 | 45.2 | 16.0 | 26.0 | 5.7 | 23.3 |
| Mild | 4.8 | 1.9 | 73.0 | 49.5 | 14.3 | 22.3 | 7.8 | 26.2 |
| Moderate | 3.0 | 0.6 | 73.5 | 55.8 | 15.5 | 26.3 | 8.1 | 17.3 |
| High | 3.8 | 0.7 | 66.5 | 52.9 | 17.1 | 21.7 | 12.6 | 24.6 |
| Extreme | 2.7 | 2.5 | 69.1 | 50.2 | 15.5 | 21.1 | 12.6 | 26.3 |
| Neighborhood food environment | | | | | | | | |
| < 0.5 miles | 3.6 | 2.1 | 70.9 | 50.7 | 15.9 | 23.2 | 9.6 | 24.1 |
| ≥ 0.5 miles | 3.0 | 1.8 | 72.4 | 52.5 | 14.9 | 21.9 | 9.7 | 23.7 |

Table 4-7: Multinomial unadjusted odds ratios of child underweight, overweight and obese at 5 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 1 (n = 3101)

| Variable | Unadjusted OR (95% CI) | | |
|--|------------------------|----------------------|----------------------|
| | Underweight | Overweight | Obese |
| Maternal socio-demographic characteristics | | | |
| Race [*] | | | |
| Black/African-American | 1.16 (0.74, 1.83) | 1.06 (0.87, 1.30) | 1.44 (1.13, 1.83) |
| Hispanic, non-Caucasian | 0.84 (0.38, 1.92) | 1.15 (0.83, 1.59) | 2.45 (1.77, 3.38) |
| Asian | 4.09 (1.71, 9.74) | 0.84 (0.40, 1.75) | 0.95 (0.40, 2.28) |
| Other | 2.33 (0.52, 10.35) | 0.56 (0.17, 1.89) | 0.95 (0.28, 3.23) |
| Married [†] | 1.26 (0.84, 1.91) | 0.88 (0.72, 1.06) | 0.68 (0.54, 0.84) |
| Education [‡] | | | |
| Less than high school | 1.57 (0.88, 2.80) | 0.97 (0.76, 1.25) | 1.16 (0.89, 1.52) |
| Any college | 1.52 (0.93, 2.52) | 0.81 (0.65, 1.01) | 0.67 (0.52, 0.86) |
| Public insurance [#] | 0.77 (0.51, 1.17) | 1.10 (0.91, 1.33) | 1.46 (1.18, 1.82) |
| Nulliparous ^{\$} | 1.59 (1.05, 2.42) | 1.22 (1.00, 1.48) | 1.22 (0.98, 1.52) |
| Maternal pre-pregnancy health characteristics | | | |
| BMI ≥ 30 kg/m ² ** | 0.82 (0.47, 1.41) | 2.04 (1.65, 2.51) | 3.46 (2.78, 4.32) |
| Pregnancy health characteristics | | | |
| Gestational diabetes ^{††} | 0.53 (0.17, 1.70) | 1.19 (0.81, 1.74) | 1.84 (1.27, 2.66) |
| Birth weight (g) ^{‡‡} | | | |
| < 1500 | 2.39 (9.71, 8.05) | 1.40 (0.67, 2.92) | 1.28 (0.55, 2.96) |
| 1500 - 2499 | 1.24 (0.63, 2.44) | 0.70 (0.47, 1.03) | 0.63 (0.40, 0.99) |
| ≥ 4000 | 0.33 (0.08, 1.36) | 1.31 (0.92, 1.87) | 1.33 (0.90, 1.96) |
| Community characteristics | | | |
| Census-tract deprivation ^{##} | | | |
| Mild | 1.11 (0.59, 2.08) | 0.98 (0.70, 1.37) | 1.56 (1.02, 2.38) |
| Moderate | 0.61 (0.30, 1.23) | 1.11 (0.81, 1.51) | 1.37 (0.91, 2.07) |
| High | 0.84 (0.42, 1.70) | 1.22 (0.88, 1.70) | 2.31 (1.55, 3.46) |
| Extreme | 0.75 (0.42, 1.33) | 1.12 (0.85, 1.47) | 2.35 (1.67, 3.33) |
| Neighborhood food environment ^{\$\$} | | | |
| ≥ 0.5 miles | 0.81 (0.49, 1.33) | 0.94 (0.76, 1.17) | 1.01 (0.79, 1.29) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; \$ Multiparous; ** < 30 kg/m²; †† No gestational diabetes; ‡‡ 2500 - 3999 g; ## minimal deprivation; \$\$ < 0.5 miles

Table 4-8: Multinomial adjusted odds ratios of child underweight versus normal weight at 5 years, aim 1 (n = 3101)

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|-----------------------|---------|-----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² ** | 0.85 (0.50, 1.45) | 0.96 (0.54, 1.56) | | 0.96 (0.56, 1.64) |
| Community characteristics | | | | |
| Census-tract deprivation ^{##} | | | | |
| Mild | 1.11 (0.54, 2.28) | 1.18 (0.58, 2.37) | | 1.19 (0.59, 2.41) |
| Moderate | 0.63 (0.27, 1.45) | 0.65 (0.28, 1.48) | | 0.65 (0.28, 1.49) |
| High | 0.85 (0.45, 1.61) | 0.90 (0.45, 1.79) | | 0.91 (0.45, 1.87) |
| Extreme | 0.79 (0.44, 1.43) | 0.80 (0.41, 1.58) | | 0.80 (0.40, 1.61) |
| Neighborhood food environment ^{\$\$} | | | | |
| ≥ 0.5 miles | 0.87 (0.50, 1.52) | 0.88 (0.48, 1.60) | | 0.86 (0.48, 1.55) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 1.67 (1.00, 2.76) | | 1.59 (0.94, 2.69) |
| Hispanic, non-Caucasian | | 1.04 (0.42, 2.64) | | 1.05 (0.41, 2.66) |
| Asian | | 3.88 (1.97, 7.65) | | 3.78 (1.90, 7.51) |
| Other | | 2.98 (0.71, 12.47) | | 2.64 (0.58, 11.92) |
| Married [†] | | 1.28 (0.77, 2.12) | | 1.34 (0.81, 2.25) |
| Education [†] | | | | |
| Less than high school | | 1.62 (0.86, 3.06) | | 1.58 (1.05, 2.40) |
| Any college | | 1.20 (0.69, 2.10) | | 1.25 (0.72, 2.19) |
| Public insurance [#] | | 0.85 (0.51, 1.41) | | 0.87 (0.52, 1.47) |
| Nulliparous ^{\$} | | 1.58 (1.06, 2.37) | | 1.58 (1.05, 2.40) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 0.54 (0.16, 1.80) |
| Birth weight (g) ^{††} | | | | |
| < 1500 | | | | 2.24 (0.58, 8.64) |
| 1500 - 2499 | | | | 1.30 (0.65, 2.60) |
| ≥ 4000 | | | | 0.33 (0.01, 1.35) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; \$ Multiparous; ** < 30 kg/m²; †† No gestational diabetes; ## 2500 - 3999 g; ## minimal deprivation; \$\$ < 0.5 miles

Table 4-9: Multinomial adjusted odds ratios of child overweight versus normal weight at 5 years, aim 1 (n = 3101)

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|----------------------|---------|----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² ** | 2.03 (1.66, 2.48) | 2.09 (1.7, 2.55) | | 2.05 (1.66, 2.54) |
| Community characteristics | | | | |
| Census-tract deprivation ^{##} | | | | |
| Mild | 0.91 (0.60, 1.39) | 0.88 (0.57, 1.35) | | 0.87 (0.57, 1.35) |
| Moderate | 1.00 (0.67, 1.48) | 0.96 (0.63, 1.47) | | 0.96 (0.63, 1.47) |
| High | 1.08 (0.72, 1.58) | 1.00 (0.67, 1.50) | | 1.00 (0.67, 1.50) |
| Extreme | 1.02 (0.71, 1.45) | 0.95 (0.63, 1.43) | | 0.96 (0.64, 1.43) |
| Neighborhood food environment ^{\$\$} | | | | |
| ≥ 0.5 miles | 0.92 (0.72, 1.16) | 0.91 (0.71, 1.15) | | 0.90 (0.71, 1.15) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 0.95 (0.74, 1.22) | | 0.97 (0.76, 1.24) |
| Hispanic, non-Caucasian | | 1.09 (0.75, 1.59) | | 1.09 (0.75, 1.58) |
| Asian | | 0.94 (0.45, 1.95) | | 0.95 (0.46, 1.97) |
| Other | | 0.53 (0.18, 1.51) | | 0.53 (.019, 1.45) |
| Married [†] | | 0.97 (0.77, 1.23) | | 0.96 (0.76, 1.20) |
| Education [†] | | | | |
| Less than high school | | 1.01 (0.77, 1.34) | | 1.02 (0.77, 1.35) |
| Any college | | 0.84 (0.66, 1.08) | | 0.84 (0.66, 1.08) |
| Public insurance [#] | | 0.97 (0.77, 1.34) | | 0.98 (0.78, 1.23) |
| Nulliparous ^{\$} | | 1.28 (1.05, 1.55) | | 1.27 (1.04, 1.56) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 1.00 (0.68, 1.47) |
| Birth weight (g) ^{††} | | | | |
| < 1500 | | | | 1.32 (0.62, 2.83) |
| 1500 - 2499 | | | | 0.71 (0.50, 1.00) |
| ≥ 4000 | | | | 1.30 (0.93, 1.82) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; \$ Multiparous; ** < 30 kg/m²; †† No gestational diabetes; ## 2500 - 3999 g; \$\$ minimal deprivation; \$\$ < 0.5 miles

**Table 4-10: Multinomial adjusted odds ratios of child obese versus normal weight at 5 years,
aim 1 (n = 3101)**

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|----------------------|---------|----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² ** | 3.26 (2.51, 4.24) | 3.52 (2.69, 4.60) | | 3.56 (2.55, 4.43) |
| Community characteristics | | | | |
| Census-tract deprivation ^{##} | | | | |
| Mild | 1.37 (0.88, 2.12) | 1.29 (0.82, 2.12) | | 1.28 (0.81, 2.01) |
| Moderate | 1.14 (0.76, 1.70) | 1.04 (0.68, 1.60) | | 1.04 (0.68, 1.59) |
| High | 1.83 (1.17, 2.86) | 1.51 (0.96, 2.38) | | 1.48 (0.94, 2.34) |
| Extreme | 1.96 (1.30, 2.97) | 1.71 (1.06, 2.67) | | 1.70 (1.05, 2.75) |
| Neighborhood food environment ^{\$\$} | | | | |
| ≥ 0.5 miles | 0.87 (0.68, 1.12) | 0.86 (0.67, 1.10) | | 0.86 (0.67, 1.10) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 0.97 (0.70, 1.34) | | 1.00 (0.72, 1.39) |
| Hispanic, non-Caucasian | | 1.91 (1.25, 2.91) | | 1.92 (1.26, 2.92) |
| Asian | | 1.22 (0.56, 2.65) | | 1.23 (0.57, 2.67) |
| Other | | 0.77 (0.17, 3.48) | | 0.77 (0.17, 3.41) |
| Married [†] | | 0.97 (0.71, 1.28) | | 0.92 (0.70, 1.22) |
| Education [†] | | | | |
| Less than high school | | 1.12 (0.81, 1.56) | | 1.12 (0.80, 1.56) |
| Any college | | 0.87 (0.67, 1.13) | | 0.86 (0.66, 1.12) |
| Public insurance [#] | | 0.97 (0.73, 1.29) | | 0.98 (0.73, 1.30) |
| Nulliparous ^{\$} | | 1.40 (1.11, 1.78) | | 1.40 (1.11, 1.78) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 1.35 (0.89, 2.07) |
| Birth weight (g) ^{††} | | | | |
| < 1500 | | | | 1.10 (0.49, 1.49) |
| 1500 - 2499 | | | | 0.64 (0.38, 1.05) |
| ≥ 4000 | | | | 1.37 (0.91, 2.07) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; \$ Multiparous; ** < 30 kg/m²; †† No gestational diabetes; ## 2500 - 3999 g; ## minimal deprivation; \$\$ < 0.5 miles

Table 4-11: Multinomial adjusted odds ratios of child BMI percentile at 5 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 1 (n = 3101)

| Variable | Adjusted OR (95% CI) | | |
|--|-----------------------|----------------------|----------------------|
| | Underweight | Overweight | Obese |
| Maternal socio-demographic characteristics | | | |
| Race* | | | |
| Black/African-American | 1.59 (0.94, 2.69) | 0.97 (0.76, 1.24) | 1.00 (0.72, 1.39) |
| Hispanic, non-Caucasian | 1.05 (0.41, 2.66) | 1.09 (0.75, 1.58) | 1.92 (1.26, 2.92) |
| Asian | 3.78 (1.90, 7.51) | 0.95 (0.46, 1.97) | 1.23 (0.57, 2.67) |
| Other | 2.64 (0.58, 11.92) | 0.53 (.019, 1.45) | 0.77 (0.17, 3.41) |
| Married † | 1.34 (0.81, 2.25) | 0.96 (0.76, 1.20) | 0.92 (0.70, 1.22) |
| Education‡ | | | |
| Less than high school | 1.58 (1.05, 2.40) | 1.02 (0.77, 1.35) | 1.12 (0.80, 1.56) |
| Any college | 1.25 (0.72, 2.19) | 0.84 (0.66, 1.08) | 0.86 (0.66, 1.12) |
| Public insurance# | 0.87 (0.52, 1.47) | 0.98 (0.78, 1.23) | 0.98 (0.73, 1.30) |
| Nulliparous§ | 1.58 (1.05, 2.40) | 1.27 (1.04, 1.56) | 1.40 (1.11, 1.78) |
| Maternal pre-pregnancy health characteristics | | | |
| BMI ≥ 30 kg/m² ** | 0.96 (0.56, 1.64) | 2.05 (1.66, 2.54) | 3.56 (2.55, 4.43) |
| Pregnancy health characteristics | | | |
| Gestational diabetes†† | 0.54 (0.16, 1.80) | 1.00 (0.68, 1.47) | 1.35 (0.89, 2.07) |
| Birth weight (g) ‡‡ | | | |
| < 1500 | 2.24 (0.58, 8.64) | 1.32 (0.62, 2.83) | 1.10 (0.49, 1.49) |
| 1500 - 2499 | 1.30 (0.65, 2.60) | 0.71 (0.50, 1.00) | 0.64 (0.38, 1.05) |
| ≥ 4000 | 0.33 (0.01, 1.35) | 1.30 (0.93, 1.82) | 1.37 (0.91, 2.07) |
| Community characteristics | | | |
| Census-tract deprivation## | | | |
| Mild | 1.19 (0.59, 2.41) | 0.87 (0.57, 1.35) | 1.28 (0.81, 2.01) |
| Moderate | 0.65 (0.28, 1.49) | 0.96 (0.63, 1.47) | 1.04 (0.68, 1.59) |
| High | 0.91 (0.45, 1.87) | 1.00 (0.67, 1.50) | 1.48 (0.94, 2.34) |
| Extreme | 0.80 (0.40, 1.61) | 0.96 (0.64, 1.43) | 1.70 (1.05, 2.75) |
| Neighborhood food environment§§ | | | |
| ≥ 0.5 miles | 0.86 (0.48, 1.55) | 0.90 (0.71, 1.15) | 0.86 (0.67, 1.10) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; § Multiparous; ** < 30 kg/m²; †† No gestational diabetes; ‡‡ 2500 - 3999 g; ## minimal deprivation; §§ < 0.5 miles

Table 4-12: Maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics of the study sample, aim 2 (n = 3862)

| Variable | N (%) |
|---|--------------|
| Child body mass index (BMI) trajectory | |
| Decline | 325 (8.42) |
| Stable | 3037 (78.64) |
| Steady gain | 308 (7.98) |
| Rapid gain | 192 (4.97) |
| Maternal socio-demographic characteristics | |
| Race | |
| Caucasian/White | 1513 (39.18) |
| Black/African-American | 1806 (46.76) |
| Hispanic, non-Caucasian | 418 (10.82) |
| Asian | 78 (2.02) |
| Other | 47 (1.22) |
| Marital status | |
| Single, widowed, divorced | 2185 (56.58) |
| Married | 1677 (43.42) |
| Education | |
| Less than high school | 905 (23.43) |
| High school graduate | 1363 (35.29) |
| Any college | 1594 (41.27) |
| Insurance | |
| Private | 1756 (45.47) |
| Public | 2106 (54.53) |
| Parity | |
| Nulliparous | 1338 (34.65) |
| Multiparous | 2524 (65.35) |
| Age (years) | |
| < 18 | 196 (5.08) |
| 18 - 34 | 3209 (83.09) |
| ≥ 35 | 457 (11.83) |
| Maternal pre-pregnancy health characteristics | |
| Pre-pregnancy BMI | |
| < 30 kg/m ² | 2878 (74.52) |
| ≥ 30 kg/m ² | 984 (25.48) |
| Chronic hypertension | |
| No | 3720 (96.32) |
| Yes | 142 (3.68) |
| Diabetes mellitus | |
| No | 3818 (98.86) |
| Yes | 44 (1.14) |
| Smoking history | |
| No | 3049 (78.95) |
| Yes | 813 (21.05) |
| Pregnancy health characteristics | |
| Gestational diabetes | |
| No | 3623 (93.81) |
| Yes | 239 (6.19) |
| Pregnancy hypertensive disorder | |
| No | 3578 (92.65) |
| Yes | 284 (7.35) |
| Birth weight (g) | |
| < 1500 | 57 (1.48) |
| 1500 - 2499 | 306 (7.92) |
| 2500 - 3999 | 3246 (84.05) |
| ≥ 4000 | 253 (6.55) |

| | |
|-------------------------------|--------------|
| Community characteristics | |
| Census-tract deprivation | |
| Minimal | 665 (17.22) |
| Mild | 579 (14.99) |
| Moderate | 690 (17.87) |
| High | 576 (14.91) |
| Extreme | 1352 (35.01) |
| Neighborhood food environment | |
| < 0.5 miles | 1038 (26.88) |
| ≥ 0.5 miles | 2824 (73.12) |
| Cohort Characteristics | |
| Birth year | |
| 2004 | 999 (25.87) |
| 2005 | 967 (25.04) |
| 2006 | 955 (24.73) |
| 2007 | 941 (24.37) |
| Follow-up (months) | |
| ≤ 36 | 995 (25.76) |
| 37 - 60 | 1956 (50.65) |
| > 60 | 911 (23.59) |

Table 4-13: Child BMI trajectory category at 5 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 2 (n = 3862)

| Variable | N (%) | | | | | p |
|---|--------------|------------|--------------|-------------|-------------|--------|
| | All | Decline | Stable | Steady gain | Rapid gain | |
| Maternal socio-demographic characteristics | | | | | | <0.001 |
| Race | | | | | | |
| Caucasian/White | 1513 (39.18) | 130 (8.59) | 1226 (81.03) | 105 (6.94) | 52 (3.44) | |
| Black/African-American | 1806 (46.76) | 127 (7.03) | 1416 (78.41) | 153 (8.47) | 110 (6.09) | |
| Hispanic, non-Caucasian | 418 (10.82) | 54 (12.92) | 297 (71.05) | 41 (9.01) | 26 (6.22) | |
| Asian | 78 (2.02) | 7 (8.97) | 62 (79.49) | 7 (8.97) | 2 (2.56) | |
| Other | 47 (1.22) | 7 (14.89) | 36 (76.60) | 2 (4.26) | 2 (4.26) | |
| Marital status | | | | | | <0.001 |
| Single, widowed, divorced | 2185 (56.58) | 184 (8.42) | 1672 (76.52) | 185 (8.47) | 144 (6.59) | |
| Married | 1677 (43.42) | 141 (8.41) | 1365 (81.40) | 123 (7.33) | 48 (2.86) | |
| Education | | | | | | 0.019 |
| Less than high school | 905 (23.43) | 73 (8.07) | 701 (77.46) | 78 (8.62) | 53 (5.86) | |
| High school graduate | 1363 (35.29) | 119 (8.73) | 1051 (77.11) | 109 (8.00) | 84 (6.16) | |
| Any college | 1594 (41.27) | 133 (8.34) | 1285 (80.61) | 121 (7.59) | 55 (3.45) | |
| Insurance | | | | | | 0.067 |
| Private | 1756 (45.47) | 147 (8.37) | 1407 (80.13) | 130 (7.40) | 72 (4.10) | |
| Public | 2106 (54.53) | 178 (8.45) | 1630 (77.40) | 178 (8.45) | 120 (5.70) | |
| Parity | | | | | | 0.485 |
| Nulliparous | 1338 (34.65) | 105 (7.85) | 1052 (78.62) | 117 (8.74) | 64 (4.78) | |
| Multiparous | 2524 (65.35) | 220 (8.82) | 1982 (78.65) | 191 (7.57) | 128 (5.07) | |
| Age (years) | | | | | | 0.977 |
| < 18 | 196 (5.08) | 18 (9.18) | 154 (78.57) | 14 (7.14) | 10 (5.10) | |
| 18 - 34 | 3209 (83.09) | 268 (8.35) | 2530 (78.84) | 255 (7.95) | 156 (4.86) | |
| ≥ 35 | 457 (11.83) | 39 (8.53) | 353 (77.24) | 39 (8.53) | 26 (5.69) | |
| Maternal pre-pregnancy health characteristics | | | | | | <0.001 |
| Pre-pregnancy BMI | | | | | | |
| < 30 kg/m ² | 2878 (74.52) | 257 (8.93) | 2338 (81.27) | 193 (6.71) | 90 (3.13) | |
| ≥ 30 kg/m ² | 984 (25.48) | 68 (6.91) | 699 (71.04) | 115 (11.69) | 102 (10.37) | |
| Chronic hypertension | | | | | | 0.091 |
| No | 3720 (96.32) | 314 (8.44) | 2933 (78.84) | 294 (7.90) | 179 (4.81) | |
| Yes | 142 (3.68) | 11 (7.75) | 104 (73.24) | 14 (9.86) | 13 (9.15) | |
| Diabetes mellitus | | | | | | 0.023 |
| No | 3818 (98.86) | 319 (8.36) | 3009 (78.81) | 304 (7.96) | 186 (4.87) | |
| Yes | 44 (1.14) | 6 (13.64) | 28 (63.64) | 4 (9.09) | 6 (13.64) | |

| | | | | | | |
|----------------------------------|--------------|-------------|--------------|-------------|------------|--------|
| Smoking history | | | | | | |
| No | 3049 (78.95) | 259 (8.49) | 2421 (79.40) | 228 (7.48) | 141 (4.62) | 0.027 |
| Yes | 813 (21.05) | 66 (8.12) | 616 (75.77) | 80 (9.84) | 51 (6.27) | |
| Pregnancy health characteristics | | | | | | |
| Gestational diabetes | | | | | | |
| No | 3623 (93.81) | 303 (8.36) | 2865 (79.08) | 279 (7.70) | 176 (4.86) | 0.034 |
| Yes | 239 (6.19) | 22 (9.21) | 172 (71.97) | 29 (12.13) | 16 (6.69) | |
| Pregnancy hypertensive disorder | | | | | | |
| No | 3578 (92.65) | 302 (8.44) | 2819 (78.79) | 279 (7.80) | 178 (4.97) | 0.553 |
| Yes | 284 (7.35) | 23 (8.10) | 218 (76.76) | 29 (10.21) | 14 (4.93) | |
| Birth weight (g) | | | | | | |
| < 1500 | 57 (1.48) | 6 (10.53) | 39 (68.42) | 9 (15.79) | 3 (5.26) | 0.648 |
| 1500 - 2499 | 306 (7.92) | 27 (8.82) | 239 (78.10) | 23 (7.52) | 17 (5.56) | |
| 2500 - 3999 | 3246 (84.05) | 267 (8.23) | 2561 (78.90) | 257 (7.92) | 161 (4.96) | |
| ≥ 4000 | 253 (6.55) | | | | | |
| Community characteristics | | | | | | |
| Census-tract deprivation | | | | | | |
| Minimal | 665 (17.22) | 65 (9.77) | 540 (81.20) | 40 (6.02) | 20 (3.01) | 0.002 |
| Mild | 579 (14.99) | 44 (7.60) | 462 (79.79) | 44 (7.60) | 29 (5.01) | |
| Moderate | 690 (17.87) | 60 (8.70) | 550 (79.71) | 57 (8.26) | 23 (3.33) | |
| High | 576 (14.91) | 48 (8.33) | 445 (77.26) | 58 (10.07) | 25 (4.34) | |
| Extreme | 1352 (35.01) | 108 (7.99) | 1040 (76.92) | 109 (8.06) | 95 (7.03) | |
| Neighborhood food environment | | | | | | |
| < 0.5 miles | 1038 (26.88) | 98 (8.42) | 812 (78.32) | 69 (6.65) | 59 (5.68) | 0.094 |
| ≥ 0.5 miles | 2824 (73.12) | 227 (8.04) | 2225 (78.79) | 239 (8.46) | 133 (4.71) | |
| Cohort characteristics | | | | | | |
| Birth year | | | | | | |
| 2004 | 999 (25.87) | 35 (3.50) | 776 (77.68) | 109 (10.91) | 79 (7.91) | <0.001 |
| 2005 | 967 (25.04) | 53 (5.48) | 776 (80.25) | 84 (8.69) | 54 (5.58) | |
| 2006 | 955 (24.73) | 82 (8.59) | 777 (81.36) | 58 (6.07) | 38 (3.98) | |
| 2007 | 941 (24.37) | 155 (16.47) | 708 (75.24) | 57 (6.06) | 21 (2.213) | |
| Follow-up (months) | | | | | | |
| ≤ 36 | 995 (25.76) | 192 (19.30) | 686 (68.94) | 77 (7.74) | 40 (4.02) | <0.001 |
| 37 - 60 | 1956 (50.65) | 125 (6.39) | 1607 (82.16) | 136 (6.95) | 88 (4.50) | |
| > 60 | 911 (23.59) | 8 (0.88) | 744 (81.67) | 95 (10.43) | 64 (7.03) | |

Table 4-14: Pre-pregnancy BMI-specific percentages of decline, stable, steady gain and rapid gain trajectories between 2 and 8 years old for children in the Delaware Mother and Baby Cohort (DMBC)

| Variable | (%) | | | | | | | |
|---|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| | Decline | | Stable | | Steady gain | | Rapid gain | |
| | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² | < 30 kg/m ² | ≥ 30 kg/m ² |
| Maternal socio-demographic characteristics | | | | | | | | |
| Race | | | | | | | | |
| Caucasian/White | 8.8 | 7.6 | 83.3 | 71.8 | 5.6 | 12.3 | 2.2 | 8.3 |
| Black/African-American | 7.7 | 5.6 | 81.7 | 71.2 | 7.0 | 11.6 | 3.6 | 11.6 |
| Hispanic, non-Caucasian | 13.1 | 13.4 | 72.6 | 66.0 | 9.4 | 11.3 | 5.0 | 10.3 |
| Asian | 8.5 | 14.3 | 78.9 | 85.7 | 9.9 | - | 2.8 | - |
| Other | 18.4 | - | 76.3 | 77.8 | 2.6 | 11.1 | 2.6 | 11.1 |
| Marital status | | | | | | | | |
| Single, widowed, divorced | 9.4 | 6.0 | 79.2 | 69.7 | 7.4 | 11.2 | 4.0 | 13.1 |
| Married | 8.4 | 8.5 | 83.7 | 73.2 | 5.9 | 12.6 | 2.1 | 5.7 |
| Education | | | | | | | | |
| Less than high school | 8.6 | 6.3 | 79.0 | 72.1 | 8.7 | 8.3 | 3.7 | 13.2 |
| High school graduate | 10.0 | 5.9 | 79.6 | 71.6 | 6.1 | 12.2 | 4.3 | 10.3 |
| Any college | 8.3 | 8.4 | 83.7 | 69.8 | 6.1 | 13.0 | 1.9 | 8.8 |
| Insurance | | | | | | | | |
| Private | 8.3 | 8.6 | 83.2 | 69.4 | 6.2 | 11.4 | 2.2 | 10.5 |
| Public | 9.5 | 5.7 | 79.5 | 72.1 | 7.1 | 11.8 | 3.9 | 10.3 |
| Parity | | | | | | | | |
| Nulliparous | 9.5 | 7.4 | 81.1 | 67.3 | 6.4 | 14.7 | 3.0 | 10.7 |
| Multiparous | 8.0 | 6.7 | 81.5 | 72.5 | 7.2 | 10.5 | 3.3 | 10.3 |
| Age (years) | | | | | | | | |
| < 18 | 8.4 | 16.7 | 81.5 | 50.0 | 7.3 | 5.6 | 2.8 | 27.8 |
| 18 - 34 | 9.0 | 6.5 | 81.2 | 72.2 | 6.7 | 11.6 | 3.2 | 9.7 |
| ≥ 35 | 8.6 | 8.4 | 81.6 | 66.4 | 6.7 | 13.0 | 3.1 | 12.2 |
| Maternal pre-pregnancy health characteristics | | | | | | | | |
| Chronic hypertension | | | | | | | | |
| No | 8.9 | 7.0 | 81.3 | 71.1 | 6.7 | 11.6 | 3.1 | 10.3 |
| Yes | 10.0 | 6.1 | 76.7 | 70.7 | 6.7 | 12.2 | 6.7 | 11.0 |
| Diabetes mellitus | | | | | | | | |
| No | 8.9 | 6.8 | 81.4 | 71.3 | 6.6 | 11.9 | 3.1 | 10.0 |
| Yes | 20.0 | 8.3 | 65.0 | 62.5 | 15.0 | 4.2 | - | 25.0 |
| Smoking history | | | | | | | | |
| No | 9.1 | 6.8 | 81.0 | 71.7 | 6.1 | 11.6 | 2.9 | 9.9 |
| Yes | 8.4 | 7.5 | 78.5 | 68.9 | 9.1 | 11.8 | 4.1 | 11.8 |

| | | | | | | | | |
|----------------------------------|------|------|------|------|------|------|-----|------|
| Pregnancy health characteristics | | | | | | | | |
| Gestational diabetes | | | | | | | | |
| No | 9.0 | 6.4 | 81.2 | 72.4 | 6.7 | 10.9 | 3.2 | 10.2 |
| Yes | 7.9 | 10.4 | 83.3 | 61.6 | 7.0 | 16.8 | 1.8 | 11.2 |
| Pregnancy hypertensive disorder | | | | | | | | |
| No | 8.9 | 6.9 | 81.3 | 71.0 | 6.6 | 11.5 | 3.2 | 10.6 |
| Yes | 8.8 | 7.0 | 80.1 | 71.0 | 8.2 | 13.2 | 2.4 | 8.8 |
| Birth weight (g) | | | | | | | | |
| < 1500 | 15.4 | – | 69.2 | 66.7 | 12.8 | 22.2 | 2.6 | 11.1 |
| 1500 – 2499 | 8.7 | 6.5 | 81.6 | 67.7 | 6.6 | 12.9 | 3.2 | 12.9 |
| 2500 – 3999 | 9.4 | 6.9 | 80.7 | 71.1 | 6.2 | 11.8 | 3.7 | 10.2 |
| ≥ 4000 | 10.5 | 8.6 | 80.2 | 74.1 | 7.6 | 7.4 | 1.7 | 9.9 |
| Community characteristics | | | | | | | | |
| Census-tract deprivation | | | | | | | | |
| Minimal | 9.3 | 5.5 | 83.7 | 66.3 | 4.9 | 12.6 | 2.1 | 8.4 |
| Mild | 7.4 | 1.9 | 82.9 | 69.4 | 6.1 | 12.7 | 3.6 | 9.7 |
| Moderate | 9.6 | 0.6 | 80.8 | 76.7 | 7.2 | 11.1 | 2.4 | 5.8 |
| High | 8.5 | 0.7 | 82.0 | 65.5 | 8.3 | 14.6 | 1.2 | 12.1 |
| Extreme | 9.3 | 2.5 | 78.9 | 72.3 | 7.2 | 10.2 | 4.8 | 12.5 |
| Neighborhood food environment | | | | | | | | |
| < 0.5 miles | 8.1 | 7.8 | 81.9 | 69.5 | 7.1 | 12.6 | 2.9 | 10.2 |
| ≥ 0.5 miles | 11.2 | 4.7 | 79.4 | 75.1 | 5.7 | 9.4 | 3.8 | 10.8 |

Table 4-15: Multinomial unadjusted odds ratios of child BMI decline, steady gain and rapid gain from 2 - 8 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 2 (n = 3862)

| Variable | Unadjusted OR (95% CI) | | |
|---|------------------------|----------------------|----------------------|
| | Decline | Steady gain | Rapid gain |
| Maternal socio-demographic characteristics | | | |
| Race [*] | | | |
| Black/African-American | 0.85 (0.65, 1.09) | 1.26 (0.97, 1.64) | 1.83 (1.31, 2.57) |
| Hispanic, non-Caucasian | 1.71 (1.22, 2.41) | 1.61 (1.10, 2.36) | 2.06 (1.27, 3.36) |
| Asian | 1.06 (0.48, 2.37) | 1.31 (0.59, 2.95) | 0.76 (0.18, 3.19) |
| Other | 1.83 (0.80, 4.20) | 0.65 (0.15, 2.73) | 1.31 (0.31, 5.59) |
| Married [†] | 0.94 (0.75, 1.18) | 0.81 (0.64, 1.03) | 0.41 (0.29, 0.57) |
| Education [‡] | | | |
| Less than high school | 0.92 (0.68, 1.25) | 1.07 (0.79, 1.46) | 0.95 (0.66, 1.35) |
| Any college | 0.91 (0.70, 1.19) | 0.91 (0.69, 1.19) | 0.54 (0.38, 0.76) |
| Maternal pre-pregnancy health characteristics | | | |
| BMI ≥ 30 kg/m ² [#] | 0.88 (0.67, 1.17) | 1.99 (1.56, 2.55) | 3.79 (2.82, 5.10) |
| Diabetes mellitus ^{\$} | 2.02 (0.83, 4.92) | 1.41 (0.49, 4.06) | 3.47 (1.42, 8.48) |
| Smoking history ^{**} | 1.00 (0.75, 1.33) | 1.38 (1.05, 1.81) | 1.42 (1.02, 1.98) |
| Pregnancy health characteristics | | | |
| Gestational diabetes ^{††} | 1.21 (0.76, 1.91) | 1.73 (1.15, 2.61) | 1.82 (1.19, 2.53) |
| Community characteristics | | | |
| Census-tract deprivation ^{‡‡} | | | |
| Mild | 0.79 (0.53, 1.18) | 1.29 (0.82, 2.01) | 1.69 (0.94, 3.04) |
| Moderate | 0.91 (0.63, 1.31) | 1.40 (0.92, 2.13) | 1.13 (0.61, 2.08) |
| High | 0.80 (0.60, 1.33) | 1.76 (1.15, 2.68) | 1.52 (0.83, 2.77) |
| Extreme | 0.86 (0.62, 1.19) | 1.41 (0.97, 2.06) | 2.47 (1.51, 4.04) |
| ≥ 0.5 miles ^{\$\$} | 1.18 (0.92, 1.52) | 0.79 (0.60, 1.05) | 1.22 (0.88, 1.67) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # BMI < 30 kg/m²; \$ No diabetes mellitus; ** No smoking history; †† No gestational diabetes; ‡‡ Minimal deprivation; \$\$ < 0.5 miles

Table 4-16: Multinomial adjusted odds ratios of declining BMI trajectory versus stable BMI trajectory, aim 2 (n = 3862) ^

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|----------------------|----------------------|----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² # | 0.89 (0.65, 1.22) | 0.90 (0.66, 1.23) | 0.90 (0.66, 1.23) | 0.89 (0.65, 1.22) |
| Community characteristics | | | | |
| Census-tract deprivation ^{††} | | | | |
| Mild | 0.77 (0.54, 1.09) | 0.77 (0.54, 1.11) | 0.77 (0.54, 1.11) | 0.77 (0.54, 1.11) |
| Moderate | 0.82 (0.57, 1.18) | 0.83 (0.57, 1.21) | 0.82 (0.56, 1.20) | 0.82 (0.56, 1.20) |
| High | 0.78 (0.57, 0.08) | 0.75 (0.52, 1.07) | 0.74 (0.52, 1.07) | 0.74 (0.51, 1.06) |
| Extreme | 0.72 (0.54, 0.96) | 0.79 (0.54, 1.15) | 0.78 (0.54, 1.14) | 0.78 (0.54, 1.14) |
| Neighborhood food environment ^{§§} | | | | |
| ≥ 0.5 miles | 1.13 (0.89, 1.44) | 1.13 (0.88, 1.44) | 1.13 (0.88, 1.44) | 1.13 (0.88, 1.44) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 0.76 (0.54, 1.08) | 0.78 (0.55, 1.08) | 0.78 (0.56, 1.09) |
| Hispanic, non-Caucasian | | 1.82 (1.22, 2.71) | 1.86 (1.26, 2.76) | 1.86 (1.26, 2.76) |
| Asian | | 0.94 (0.43, 2.05) | 0.95 (0.44, 2.07) | 0.95 (0.44, 2.07) |
| Other | | 1.29 (0.53, 3.10) | 1.30 (0.54, 3.13) | 1.30 (0.54, 3.16) |
| Married [†] | | 0.99 (0.74, 1.35) | 0.99 (0.74, 1.35) | 1.00 (0.74, 1.37) |
| Education [†] | | | | |
| Less than high school | | 0.75 (0.53, 1.07) | 0.75 (0.53, 1.07) | 0.75 (0.53, 1.07) |
| Any college | | 0.85 (0.62, 1.18) | 0.85 (0.62, 1.19) | 0.85 (0.62, 1.19) |
| Maternal pre-pregnancy health characteristics | | | | |
| Diabetes mellitus [§] | | | 1.14 (0.48, 2.70) | 1.14 (0.48, 2.70) |
| Smoking history ^{**} | | | 1.10 (0.81, 1.50) | 1.10 (0.81, 1.50) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 1.21 (0.73, 2.01) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # BMI < 30 kg/m²; § No diabetes mellitus; ** No smoking history; †† No gestational diabetes; §§ Minimal deprivation; §§ < 0.5 miles; ^ adjusted for birth year and follow-up duration

Table 4-17: Multinomial adjusted odds ratios of steady gain trajectory versus stable BMI trajectory, aim 2 (n = 3862) ^

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|----------------------|----------------------|----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² # | 1.94 (1.53, 2.46) | 1.96 (1.55, 2.49) | 1.95 (1.53, 2.47) | 1.87 (1.46, 2.39) |
| Community characteristics | | | | |
| Census-tract deprivation ^{††} | | | | |
| Mild | 1.16 (0.83, 1.62) | 1.13 (0.80, 1.61) | 1.12 (0.79, 1.58) | 1.12 (0.79, 1.59) |
| Moderate | 1.32 (0.98, 1.79) | 1.25 (0.90, 1.74) | 1.25 (0.89, 1.72) | 1.23 (0.89, 1.71) |
| High | 1.54 (1.03, 2.31) | 1.37 (0.88, 2.13) | 1.33 (0.85, 2.07) | 1.31 (0.83, 2.05) |
| Extreme | 1.36 (1.06, 1.75) | 1.20 (0.86, 1.67) | 1.17 (0.83, 1.65) | 1.16 (0.83, 1.64) |
| Neighborhood food environment ^{§§} | | | | |
| ≥ 0.5 miles | 0.77 (0.58, 1.00) | 0.76 (0.57, 0.99) | 0.75 (0.57, 0.99) | 0.75 (0.57, 0.99) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 1.10 (0.82, 1.49) | 1.15 (0.86, 1.56) | 1.17 (0.86, 1.58) |
| Hispanic, non-Caucasian | | 1.51 (1.05, 2.17) | 1.64 (1.14, 2.38) | 1.65 (1.14, 2.38) |
| Asian | | 1.52 (0.69, 3.38) | 1.57 (0.71, 3.49) | 1.57 (0.71, 3.47) |
| Other | | 0.66 (0.15, 2.87) | 0.69 (0.17, 2.99) | 0.68 (0.15, 3.01) |
| Married [†] | | 0.85 (0.62, 1.15) | 0.88 (0.65, 1.20) | 0.87 (0.64, 1.17) |
| Education [†] | | | | |
| Less than high school | | 1.08 (0.77, 1.50) | 1.07 (0.76, 1.47) | 1.05 (0.76, 1.47) |
| Any college | | 1.15 (0.83, 1.59) | 1.19 (0.86, 1.64) | 1.19 (0.86, 1.64) |
| Maternal pre-pregnancy health characteristics | | | | |
| Diabetes mellitus [§] | | | 1.36 (0.49, 3.81) | 1.15 (0.39, 3.44) |
| Smoking history ^{**} | | | 1.35 (1.06, 1.73) | 1.36 (1.06, 1.73) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 1.54 (1.02, 2.32) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # BMI < 30 kg/m²; § No diabetes mellitus; ** No smoking history; †† No gestational diabetes; ‡‡ Minimal deprivation; §§ < 0.5 miles; ^ adjusted for birth year and follow-up duration

Table 4-18: Multinomial adjusted odds ratios of accelerated gain trajectory versus stable BMI trajectory, aim 2 (n = 3862) ^

| Variable | Adjusted OR (95% CI) | | | |
|---|----------------------|----------------------|----------------------|----------------------|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Maternal pre-pregnancy body mass index (BMI) | | | | |
| BMI ≥ 30 kg/m ² # | 3.67 (2.64, 5.11) | 3.65 (2.62, 5.09) | 3.54 (2.56, 4.90) | 3.49 (2.51, 4.85) |
| Community characteristics | | | | |
| Census-tract deprivation ^{††} | | | | |
| Mild | 1.43 (0.74, 2.78) | 1.22 (0.62, 2.39) | 1.20 (0.61, 2.35) | 1.20 (0.61, 2.35) |
| Moderate | 0.94 (0.52, 1.71) | 0.73 (0.40, 1.32) | 0.72 (0.40, 1.31) | 0.72 (0.40, 1.32) |
| High | 1.24 (0.68, 2.24) | 0.79 (0.40, 1.49) | 0.78 (0.40, 1.49) | 0.78 (0.40, 1.49) |
| Extreme | 2.00 (1.16, 3.44) | 1.22 (0.65, 2.28) | 1.22 (0.65, 2.29) | 1.22 (0.65, 2.29) |
| Neighborhood food environment ^{§§} | | | | |
| ≥ 0.5 miles | 1.00 (0.73, 1.40) | 0.94 (0.68, 1.30) | 0.93 (0.67, 1.29) | 0.93 (0.67, 1.29) |
| Maternal socio-demographic characteristics | | | | |
| Race [†] | | | | |
| Black/African-American | | 1.10 (0.69, 1.73) | 1.10 (0.69, 1.75) | 1.11 (0.70, 1.76) |
| Hispanic, non-Caucasian | | 1.69 (0.95, 2.98) | 1.73 (0.98, 3.04) | 1.73 (0.98, 3.04) |
| Asian | | 1.20 (0.29, 4.95) | 1.21 (0.29, 5.02) | 1.21 (0.29, 5.02) |
| Other | | 1.55 (0.34, 6.98) | 1.52 (0.34, 6.81) | 1.51 (0.33, 6.89) |
| Married [†] | | 0.47 (0.32, 0.68) | 0.47 (0.32, 0.70) | 0.47 (0.32, 0.69) |
| Education [†] | | | | |
| Less than high school | | 0.94 (0.66, 1.34) | 0.94 (0.66, 1.33) | 0.94 (0.67, 1.33) |
| Any college | | 0.95 (0.64, 1.41) | 0.96 (0.64, 1.42) | 0.96 (0.64, 1.42) |
| Maternal pre-pregnancy health characteristics | | | | |
| Diabetes mellitus [§] | | | 3.73 (1.63, 8.53) | 2.48 (1.48, 8.18) |
| Smoking history ^{**} | | | 1.07 (0.74, 1.56) | 1.07 (0.73, 1.56) |
| Pregnancy health characteristics | | | | |
| Gestational diabetes ^{††} | | | | 1.21 (0.67, 2.19) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # BMI < 30 kg/m²; § No diabetes mellitus; ** No smoking history; †† No gestational diabetes; ‡‡ Minimal deprivation; §§ < 0.5 miles; ^ adjusted for birth year and follow-up duration

4-19: Multinomial adjusted odds ratios of child BMI decline, steady gain and rapid gain from 2 - 8 years by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 2 (n = 3862)

| Variable | Adjusted OR (95% CI) ^ | | |
|--|------------------------|----------------------|----------------------|
| | Decline | Steady gain | Rapid gain |
| Maternal socio-demographic characteristics | | | |
| Race* | | | |
| Black/African-American | 0.78 (0.56, 1.09) | 1.17 (0.86, 1.58) | 1.11 (0.70, 1.76) |
| Hispanic, non-Caucasian | 1.86 (1.26, 2.76) | 1.65 (1.14, 2.38) | 1.73 (0.98, 3.04) |
| Asian | 0.95 (0.44, 2.07) | 1.57 (0.71, 3.47) | 1.21 (0.29, 5.02) |
| Other | 1.30 (0.54, 3.16) | 0.68 (0.15, 3.01) | 1.51 (0.33, 6.89) |
| Married† | 1.00 (0.74, 1.37) | 0.87 (0.64, 1.17) | 0.47 (0.32, 0.69) |
| Education‡ | | | |
| Less than high school | 0.75 (0.53, 1.07) | 1.05 (0.76, 1.47) | 0.94 (0.67, 1.33) |
| Any college | 0.85 (0.62, 1.19) | 1.19 (0.86, 1.64) | 0.96 (0.64, 1.42) |
| Maternal pre-pregnancy health characteristics | | | |
| BMI ≥ 30 kg/m ² # | 0.89 (0.65, 1.22) | 1.87 (1.46, 2.39) | 3.49 (2.51, 4.85) |
| Diabetes mellitus§ | 1.14 (0.48, 2.70) | 1.15 (0.39, 3.44) | 2.48 (1.48, 8.18) |
| Smoking history** | 1.10 (0.81, 1.50) | 1.36 (1.06, 1.73) | 1.07 (0.73, 1.56) |
| Pregnancy health characteristics | | | |
| Gestational diabetes†† | 1.21 (0.73, 2.01) | 1.54 (1.02, 2.32) | 1.21 (0.67, 2.19) |
| Community characteristics | | | |
| Census-tract deprivation‡‡ | | | |
| Mild | 0.77 (0.54, 1.11) | 1.12 (0.79, 1.59) | 1.20 (0.61, 2.35) |
| Moderate | 0.82 (0.56, 1.20) | 1.23 (0.89, 1.71) | 0.72 (0.40, 1.32) |
| High | 0.74 (0.51, 1.06) | 1.31 (0.83, 2.05) | 0.78 (0.40, 1.49) |
| Extreme | 0.78 (0.54, 1.14) | 1.16 (0.83, 1.64) | 1.22 (0.65, 2.29) |
| Neighborhood food environment§§ | | | |
| ≥ 0.5 miles | 1.13 (0.88, 1.44) | 0.75 (0.57, 0.99) | 0.93 (0.67, 1.29) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # BMI < 30 kg/m²; § No diabetes mellitus; ** No smoking history; †† No gestational diabetes; ‡‡ Minimal deprivation; §§ < 0.5 miles; ^ adjusted for birth year and follow-up duration

Table 4-20: Maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics of the study sample by mean pre-pregnancy BMI and pre-pregnancy BMI category, supplemental analysis of DMBC mothers (n = 4770)

| Variable | N (%) | Mean (sd) | < 30 kg/m ² | ≥ 30 kg/m ² | p |
|---|--------------|--------------|------------------------|------------------------|---------|
| Maternal socio-demographic characteristics | | | | | |
| Race | | | | | |
| Caucasian/White | 1875 (39.31) | 25.62 (6.23) | 1497 (79.84) | 378 (20.16) | < 0.001 |
| Black/African-American | 2179 (45.68) | 27.96 (7.73) | 1486 (68.20) | 693 (31.80) | |
| Hispanic, non-Caucasian | 528 (11.07) | 26.30 (6.04) | 410 (77.65) | 118 (22.35) | |
| Asian | 119 (2.49) | 23.39 (4.81) | 109 (91.60) | 10 (8.40) | |
| Other | 69 (1.45) | 26.43 (6.90) | 54 (78.26) | 15 (21.74) | |
| Marital status | | | | | |
| Single, widowed, divorced | 2683 (56.25) | 27.07 (7.36) | 1938 (72.23) | 745 (27.77) | < 0.001 |
| Married | 2087 (43.75) | 26.27 (6.53) | 1618 (77.53) | 469 (22.47) | |
| Education | | | | | |
| Less than high school | 1137 (23.84) | 27.43 (7.43) | 878 (77.22) | 259 (22.78) | < 0.001 |
| High school graduate | 1679 (35.20) | 26.35 (6.61) | 1164 (69.33) | 515 (30.67) | |
| Any college | 1954 (40.96) | 26.31 (7.00) | 1514 (77.48) | 440 (22.52) | |
| Insurance | | | | | |
| Private | 2121 (44.47) | 26.19 (6.52) | 1643 (77.46) | 478 (22.54) | < 0.001 |
| Public | 2649 (55.53) | 27.15 (7.37) | 1913 (72.22) | 736 (27.78) | |
| Parity | | | | | |
| Nulliparous | 1679 (35.20) | 27.23 (7.17) | 1334 (79.45) | 345 (20.55) | < 0.001 |
| Multiparous | 3091 (64.80) | 25.77 (6.63) | 2222 (71.89) | 869 (28.11) | |
| Age (years) | | | | | |
| < 18 | 238 (4.99) | 24.10 (4.98) | 216 (70.76) | 22 (9.24) | < 0.001 |
| 18 – 34 | 3978 (83.40) | 26.78 (7.08) | 2943 (73.98) | 1035 (26.02) | |
| ≥ 35 | 554 (11.61) | 27.46 (7.14) | 397 (71.66) | 157 (28.34) | |
| Maternal pre-pregnancy health characteristics | | | | | |
| Chronic hypertension | | | | | |
| No | 4582 (96.06) | 26.44 (6.76) | 3478 (75.91) | 1104 (24.09) | < 0.001 |
| Yes | 188 (3.94) | 33.44 (9.44) | 78 (41.49) | 110 (58.51) | |
| Diabetes mellitus | | | | | |
| No | 4713 (98.81) | 26.65 (6.99) | 3529 (74.88) | 1184 (25.12) | < 0.001 |
| Yes | 57 (1.19) | 32.18 (7.63) | 27 (47.37) | 30 (52.63) | |
| Smoking history | | | | | |
| No | 3743 (78.47) | 26.63 (6.96) | 2826 (75.50) | 917 (24.50) | < 0.001 |
| Yes | 1027 (21.53) | 27.04 (7.24) | 730 (71.08) | 297 (29.92) | |
| Community characteristics | | | | | |
| Census-tract deprivation | | | | | |
| Minimal | 801 (16.79) | 24.88 (5.73) | 686 (85.64) | 115 (14.36) | < 0.001 |
| Mild | 731 (15.32) | 26.38 (6.80) | 560 (76.61) | 171 (23.39) | |
| Moderate | 863 (18.09) | 26.73 (6.61) | 628 (72.77) | 235 (27.23) | |
| High | 740 (15.51) | 26.92 (6.85) | 531 (71.76) | 209 (28.24) | |
| Extreme | 1635 (34.28) | 27.68 (7.76) | 1151 (70.40) | 484 (29.60) | |
| Neighborhood food environment | | | | | |
| < 0.5 miles | 1517 (31.80) | 26.66 (6.88) | 2443 (75.10) | 810 (24.90) | 0.201 |
| ≥ 0.5 miles | 3253 (68.20) | 26.72 (7.01) | 1113 (73.37) | 404 (26.63) | |

Table 4-21: Logistic unadjusted odds ratios of maternal BMI ≥ 30 kg/m² by maternal socio-demographic, pre-pregnancy health and neighborhood characteristics, supplemental analysis (n = 4770)

| Variable | OR (95% CI) |
|---|----------------------|
| Maternal socio-demographic characteristics | |
| Race* | |
| Black/African-American | 1.85 (1.60, 2.13) |
| Hispanic, non-Caucasian | 1.14 (0.90, 1.43) |
| Asian | 0.36 (0.19, 0.70) |
| Other | 1.10 (0.61, 1.97) |
| Married† | 0.75 (0.66, 0.86) |
| Education‡ | |
| Less than high school | 0.67 (0.56, 0.79) |
| Any college | 0.66 (0.57, 0.76) |
| Public§ | 1.32 (1.16, 1.51) |
| Nulliparous§ | 0.66 (0.57, 0.76) |
| Age** (years) | |
| < 18 | 0.29 (0.19, 0.45) |
| ≥ 35 | 1.12 (0.92, 1.37) |
| Maternal pre-pregnancy health characteristics | |
| Chronic hypertension†† | 4.44 (3.30, 5.99) |
| Diabetes mellitus†† | 3.31 (1.96, 5.59) |
| Smoking## | 1.25 (1.07, 1.46) |
| Community characteristics | |
| Census-tract deprivation §§ | |
| Mild | 1.82 (1.40, 2.37) |
| Moderate | 2.23 (1.74, 2.86) |
| High | 2.34 (1.82, 3.03) |
| Extreme | 2.50 (2.00, 3.14) |
| Neighborhood food environment §§ | |
| ≥ 0.5 miles | 1.09 (0.95, 1.26) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; § Private insurance; § Multiparous; ** Age 18 - 24; †† No chronic hypertension; ## No diabetes mellitus; ## No smoking; §§ Minimal deprivation; §§ < 0.5 miles

Table 4-22: Logistic adjusted odds ratios of maternal BMI ≥ 30 kg/m² by maternal socio-demographic, pre-pregnancy health and neighborhood characteristics, supplemental analysis (n = 4770)

| Variable | aOR (95% CI) |
|---|----------------------|
| Maternal socio-demographic characteristics | |
| Race [*] | |
| Black/African-American | 1.58 (1.32, 1.89) |
| Hispanic, non-Caucasian | 1.03 (0.80, 1.34) |
| Asian | 0.37 (0.19, 0.73) |
| Other | 1.02 (0.56, 1.86) |
| Married [†] | 1.00 (0.84, 1.20) |
| Education [‡] | |
| Less than high school | 0.74 (0.62, 0.90) |
| Any college | 0.82 (0.69, 0.98) |
| Public [#] | 1.01 (0.85, 1.21) |
| Nulliparous ^{\$} | 0.81 (0.69, 0.94) |
| Age ^{**} (years) | |
| < 18 | 0.33 (0.20, 0.53) |
| ≥ 35 | 1.22 (0.98, 1.52) |
| Maternal pre-pregnancy health characteristics | |
| Chronic hypertension ^{††} | 3.60 (2.64, 4.90) |
| Diabetes mellitus ^{††} | 2.65 (1.51, 4.65) |
| Smoking ^{##} | 1.13 (0.96, 1.34) |
| Community characteristics | |
| Census-tract deprivation ^{\$\$} | |
| Mild | 1.68 (1.28, 2.19) |
| Moderate | 1.96 (1.51, 2.54) |
| High | 1.92 (1.46, 2.54) |
| Extreme | 1.88 (1.44, 2.46) |
| Neighborhood food environment ^{\$\$} | |
| ≥ 0.5 miles | 0.91 (0.78, 1.06) |

Ref: * Caucasian/White; † single, widowed or divorced; ‡ High school graduate; # Private insurance; \$ Multiparous; ** Age 18 - 24; †† No chronic hypertension; ## No diabetes mellitus; ## No smoking; \$\$ Minimal deprivation; \$\$ < 0.5 miles

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5. Study Conclusions, future research and implications for policy and practice

Risk factors associated with obesity and BMI trajectory in children are multi-factorial and span childhood (Dixon, 2012; Perez-Escamilla, 2013). Maternal factors, such as pre-pregnancy BMI, have been consistently shown to impact risk of childhood obesity (Ehrenthal, 2013; Heerman, 2014; Yu, 2013). Neighborhood characteristics, including socioeconomic deprivation and accessibility to healthy food, have also been associated with childhood weight status (Booth, 2005; Singh, 2010; Grow, 2010). Because many neighborhood characteristics represent shared mother and child exposures, the association between maternal pre-pregnancy BMI and childhood BMI may, in part, be a result of environmental influences common to woman and child. The goal of this thesis was to evaluate the independent influence of maternal pre-pregnancy BMI and community characteristics, specifically census-tract socioeconomic deprivation and neighborhood food environment, on childhood BMI and BMI trajectory.

This chapter summarizes study methodology and results as well as reviews findings within the context of existing literature on maternal and community factors associated with BMI and BMI trajectory in children. The strength and limitations of the research and opportunities for future inquiry are discussed followed by policy and practice implications.

Summary of study methodology

This research used the Delaware Mother and Baby Cohort (DMBC), a longitudinal mother and child paired database of women who delivered at a large tertiary care center in Delaware between December 2004 and

December 2007 and who accessed pediatric care for their child through a multi-specialty pediatrics practice (NCHS) in the State between January 2004 and May 2011. Data from the two sites were linked with birth certificate data, 2010 US Census data, and a Delaware registry of healthy food outlets to examine the independent influence of maternal pre-pregnancy BMI, census-tract socioeconomic deprivation and neighborhood food environment with BMI percentile at 5-years old and BMI trajectory for 2 to 8 year-old children. To better understand the relation between these three factors, the association between each community characteristic (census-tract socioeconomic deprivation and neighborhood food environment) and maternal pre-pregnancy BMI was also explored.

There were two outcome variables. For Specific Aim 1, BMI of children 5-year of age was categorized as a multichotomous variable corresponding to the age- and sex-standardized BMI percentile cutoff values accepted for underweight ($< 5^{\text{th}}$ percentile), normal weight (5 - 84.9^{th} percentile), overweight ($85 - 94.9^{\text{th}}$ percentile) and obese ($\geq 95^{\text{th}}$ percentile). For Specific Aim 2, BMI trajectory from children 2 to 8 years was categorized as a multichotomous variable with cutoff values for the rate of change guided by previous research as well as the practical utility of a BMI trajectory metric for public health and clinical practice. The four BMI trajectory categories were decline ($> 0.05 \text{ kg/m}^2/\text{month}$), stable ($-0.05 - 0.05 \text{ kg/m}^2/\text{month}$), steady gain ($0.05 - 0.10 \text{ kg/m}^2/\text{month}$) and rapid gain ($\geq 0.10 \text{ kg/m}^2/\text{month}$).

The main independent variables for both aims were self-reported maternal pre-pregnancy BMI, community census-tract deprivation and neighborhood food environment. Maternal pre-pregnancy BMI was analyzed as a dichotomous variable such that women with a BMI $\geq 30 \text{ kg/m}^2$ were categorized as obese. An index of community census-tract socioeconomic

deprivation was created using methodology previously explained by Messer et al (Messer, 2006). This continuous index was grouped into quintiles such that each census tract was categorized by minimal, mild, moderate, high or extreme socioeconomic deprivation. Neighborhood food environment was measured using the Delaware Healthy Toolkit Food Resource Database, a list of 190 healthy food retailers distributed throughout the state. Food outlets were included on this list if they were registered by the state as a grocery store (i.e. Giant), big-box food outlet (i.e. Costco) or a local farmers market. The distance between the address of each maternal-child pair and the closest food venue was mapped and the residence of mother-child pairs at the time of the child's birth was categorized into two groups: ≤ 0.5 miles from the nearest healthy food outlet and > 0.5 miles from the nearest healthy food outlet.

The dependent variables for Specific Aim 1 and 2 were operationalized as nominal categories. Unadjusted multinomial regression was performed to determine the influence of maternal socio-demographic, pre-pregnancy health, pregnancy health and community characteristics on child weight status at 5-years and BMI trajectory from 2 to 8 years old. Variables significant in unadjusted analyses were included in multivariable multinomial logistic regression models for each aim. All analyses were performed using Stata/IC Version 13.0 and Comprehensive R Achieve Network (R) Version 3.4.2.

This study was originally approved by the Christiana Care Health System (CCHS) Institutional Review Board and then transferred to the University of Wisconsin, Madison in September 2016. Reciprocity was granted by the Office of Ethics at the Johns Hopkins Bloomberg School of Public Health (IRB-X) for both the CCHS and the University of Wisconsin - Madison IRBs.

Summary of results

The independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on the BMI of children at 5-years was investigated in Specific Aim 1. Maternal pre-pregnancy BMI ≥ 30 kg/m² was strongly associated with overweight and obesity of children at 5-years but was not associated with being underweight. Children who resided in communities characterized by extreme socio-economic deprivation had significantly higher odds of obesity compared to their counterparts in less deprived communities but did not differ for the odds of being underweight or overweight. In addition, maternal parity and race were associated with obesity at 5-years. Children born to nulliparous women had higher odds of being underweight, overweight and obese than children born to multiparous women. Children born to non-Hispanic women had higher odds of obesity than children born to white/Caucasian women but did not differ in relation to being underweight or overweight. Finally, children born to Asian women had higher odds of underweight than children born to white/Caucasian women but did not differ in terms of being overweight or obese (**Table 4-11**).

Specific aim 2 investigated the independent association of maternal pre-pregnancy obesity, census-tract socioeconomic deprivation and neighborhood food environment on child BMI trajectories from 2 to 8 years old. Maternal pre-pregnancy BMI was strongly associated with increased odds of steady gain and rapid gain BMI trajectories in the study children but not declining weight gain. Maternal diabetes mellitus was also associated with increased odds of rapid gain BMI trajectory but not declining or steady weight gain. Neither census-tract socio-economic deprivation nor neighborhood food environment was associated with child BMI trajectory. Children of Hispanic women had

increased odds of BMI decline and steady gain BMI trajectory, but not rapid gain BMI trajectory. (**Table 4-19**)

In supplemental logistic regression analysis performed to better understand the relation between maternal pre-pregnancy BMI and community characteristics, maternal pre-pregnancy BMI was significantly associated with census-tract socio-economic deprivation such that women living in more deprived communities had higher odds of BMI ≥ 30 kg/m². There was no association between maternal pre-pregnancy BMI and neighborhood food environment. Other maternal characteristics associated with increased odds of pre-pregnancy obesity were black/African-American race, chronic hypertension and diabetes mellitus. Asian race was associated with decreased odds of pre-pregnancy obesity.

Discussion of results

In this study of over 3,000 women and child pairs linked to United States Census data and neighborhood healthy food outlet data, maternal pre-pregnancy BMI, as assessed by BMI calculation based on self-reported maternal pre-pregnancy weight and height, was the strongest predictor of childhood BMI at 5-years as well as of steady and rapid gain BMI trajectories from 2 to 8 years. Moreover, residing in the most deprived neighborhoods was independently associated with increased odds of obesity in 5-year-old children; however, it was not associated with steady or rapid BMI gain from 2 to 8 years old. Neighborhood food environment was not associated with childhood BMI at 5-years old or BMI trajectory from 2 to 8 years old.

Maternal pre-pregnancy BMI and obesity in childhood

The association between maternal pre-pregnancy BMI and weight status at various ages in children has been evaluated in many observational studies. In a comprehensive review of the literature by Baidal et al, 38 articles were cited which evaluated the impact of maternal pre-pregnancy BMI on obesity in children in the first 1000 days of life (Baidal, 2016). Maternal pre-pregnancy BMI had a consistent positive relation with overweight and obesity in 34 of the 38 investigations. The authors state that of the four studies which found null associations all had limited external validity as they evaluated unique populations (for example, multiple gestations) or were performed within the context of a randomized trial.

In 2013, Ehrenthal and colleagues used the DMBC to examine the independent effects of gestational characteristics on obesity risk in 4-year old children (Ehrenthal, 2013). In this work, maternal pre-pregnancy BMI was significantly associated with offspring BMI z-score at age 4 after adjusting for pre-gestational and gestational diabetes, pregnancy induced hypertension disorders, tobacco use, net gestational weight gain adjusted, infant sex and maternal demographic characteristics. The authors concluded that maternal pre-pregnancy BMI had a greater effect on obesity in children than gestational factors. They, however, did not adjust for birth weight.

Similar findings were reported in several studies including in the work of Hawkins et al who found that maternal overweight was associated with 37% higher odds of obesity among 3-year old childhood after adjusting for maternal ethnicity, socioeconomic status, household income, highest academic qualification, age, marital status, number of

children in the household, smoking status and birth weight. (Hawkins, 2008). Reilly et al also found that children of women with a pre-pregnancy BMI indicating obesity had 4.25 increased odds of obesity at age 7 after adjusting for maternal socioeconomic status, education, birth weight, sex, parity and smoking status (Reilly, 2013). Rooney et al found that children of mothers who were obese prior to pregnancy had a 2.36 times higher risk of overweight between ages 9 and 14 (Rooney, 2011). Consistent with existing literature, our work finds a strong, direct association between maternal pre-pregnancy BMI and child obesity at 5 years old.

Neighborhood characteristics and obesity in children

Our study extends the literature showing a direct association between neighborhood socioeconomic status/deprivation and obesity in older children. In a study by Kinra et al of 20,973 children living in Plymouth, United Kingdom, community deprivation was directly associated with increased obesity rates in children ages 5 - 14 years (Kinra, 2000). The observed association was stronger among female children and increased with age in adolescent girls but not in adolescent boys.

Grow et al studied 8,616 children in King County, Washington in 2006 to estimate risk of child obesity associated with multiple census-tract socioeconomic status measures. In adjusted models, the authors found that obesity among 6 to 18 year-old children was significantly associated with census-tract measures of median household income, home ownership, adult female education level, single parent households and race (Grow, 2010). These findings are consistent with the work of Shih et al who evaluated the association between community-level economic

hardship and obesity in almost 300,000 5th, 7th and 9th grade children in Los Angeles County, California. In this investigation, lower income and higher community-level economic hardship was associated with higher obesity prevalence ($p < 0.001$) (Shih, 2013). The direct association between socioeconomic status and childhood obesity has been well researched with consistent results spanning various populations (Conrad and Capewell, 2012; Cetanteanu, 2014; Cummings, 2005; Singh, 2010; Pearce, 2007), although among children older than those included in our sample. Our work is consistent with this research as greater neighborhood deprivation was associated with increased odds of obesity in 5-year old children.

Our measure of neighborhood deprivation was independently associated with BMI of children at 5-years; however, it was not significantly associated with BMI trajectory in children 2 to 8 years after adjusting for maternal covariates. Although we found no association between neighborhood deprivation and BMI trajectory, it is possible that short follow-up compromised the complete characterization of their BMI trajectory and longer evaluation is necessary to better evaluate this relation. Alternatively, it is possible that deprivation plays a greater role in BMI change during adolescence, when children have greater autonomy in eating and exercise practices.

Our work employed a unique deprivation index to more comprehensively assess neighborhood socio-economic deprivation. Scant research had evaluated the relation between neighborhood characteristics and maternal pre-pregnancy characteristics and none had explicitly evaluated the relation between maternal census-tract deprivation or food environment and pre-pregnancy BMI. The association between neighborhood deprivation and BMI among low-income reproductive

age women was evaluated by Fort et al in a 2011 study of all Kansas mothers enrolled in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) between 2004 and 2006. (Ford, 2011) In this study of over 23,000 maternal-child dyads, a census-tract deprivation index and geospatial proximity to supermarkets and small grocery stores was evaluated in relation to maternal BMI post-partum, measured at the time of WIC enrollment during the delivery hospitalization. As hypothesized by study authors, there was a strong association between high census-tract deprivation and BMI among WIC mothers living in metropolitan areas. Among women residing in rural areas, high and low census-tract deprivation was associated with higher BMI among study participants.

Our study used data from a Delaware mapping initiative to examine the extent to which proximity to healthy food outlets such as grocery stores and farmer's markets was associated with BMI. Previous work using similar measures revealed mixed results. Feichtner and colleagues found that living near large and small supermarkets was associated with lower BMI among over 50,000 children residing in Eastern Massachusetts. Liu et al (2007) found that among over 7000 children in Marion County, Indiana increased distance between a child's residence and the nearest large brand name supermarkets was associated with increased odds of overweight, but only for children living in rural areas (Feitchner, 2013; Liu, 2007). In contrast, Epstein et al (2012) evaluated the relations between the built environment and changes in CDC standardized BMI in a sample of 191, 8 - 12-year-olds who participated in one of four randomized control trials on pediatric weight management. At 2-year follow up, fewer supermarkets were associated with a greater BMI

reduction; thus, decreased access to healthy food environment was associated with increased weight loss (Epstein, 2012).

The relation between the number of healthy and unhealthy food outlets and maternal weight was evaluated in a 2001 – 2002 study of birth certificate data linked to hospital delivery data among 210,000 New York City women (Janevic, 2010). The findings showed an increased odds of pre-pregnancy weight > 200 pounds among women living in neighborhoods with no or only one healthy food outlet compared to those residing in neighborhoods with \geq healthy food outlets. Proximity to food outlets which sell calorically dense and nutritionally poor (convenience stores), however, was not associated with pre-pregnancy weight.

While there is enthusiasm to identify an association between local food environment and obesity as evidenced by many studies on the topic, limited evidence exists for the association in both children and adults. Although it is possible that there is no association between food environment and childhood obesity, it is also likely that inadequate measurement of food environment is a reason for the null findings.

Finally, our work represents the first study that explicitly includes both maternal and neighborhood characteristics in the same statistical model to determine the independent influence of each on child obesity and child BMI trajectory. Limitations in population-based data often prevent multi-level and prospective observational cohort study. The Delaware Mother and Baby Cohort (DMBC) is a unique dyadic dataset that integrated maternal obstetric data abstracted directly from the maternal electronic medical record with longitudinal child

anthropometric data collected during pediatric visits. The opportunity to merge these diverse data with neighborhood information from the US Census data and Delaware food environment mapping initiatives allowed us to evaluate the independent effects of maternal pre-pregnancy BMI and neighborhood characteristics on child BMI in the same risk model.

While observational research cannot clarify causal relations between independent and dependent variables, evaluating the direction and strength of association between maternal socio-demographic, pre-pregnancy health, pregnancy health and community characteristics and child weight status and BMI trajectory in prospective cohort studies improves understanding of the independent roles that maternal and neighborhood characteristics play in child health. This work showed that maternal pre-pregnancy BMI and census-tract socio-economic deprivation, but not neighborhood food environment, were independently associated with child weight status among 5-year-old children.

Limitations of the study

Several limitations of our research should be considered. First, though socio-economic influences may extend beyond census-tract borders, measurement of neighborhood characteristics requires identification of clear neighborhood boundaries. This constraint, known as the Modifiable Areal Unit Problem, occurs in every spatial analysis (Fotheringham, 1991; Yang, 2005). Census-tracts were used in this work after discussions with Delaware mapping experts clarified the concordance between Delaware tract boundaries and citizen confirmed social neighborhood limits. Research shows that the accuracy of deprivation indices is improved when using higher resolution data with smaller,

more numerous spatial units (Bracken, 1989; Hyndman, 1997; Longley, 2003; Schuurman). Though neighborhood characteristics were obtained from the United States census, and tract-level data are accepted as an appropriately small spatial unit to minimize misclassification that may result from boundary imprecision and inaccuracy, bias may result from systematic error in the mapping of tract boundaries based on geospatial constraints and/or criteria used to map census-tracts.

Second, maternal address at delivery was used to map to neighborhood characteristics and does not account for residential mobility throughout the first 5-years of the child's life. The methodology employed in this study assumed no movement outside of the delivery-defined census tract. Without longitudinal address information, it was impossible to determine the dyads who remained in the census-tract of residence at delivery or who had moved. While dyadic relocation is possible, discussion with key informants in the Delaware suggested that within-tract migration is much more common than between-tract migration and thus, posed less of a concern in this research (West, 2013).

An additional limitation of the use of maternal address at delivery is the assumed concordance between the mother's and child's address. Indeed, most children resided in the maternal household during childhood; however, it is not uncommon for children of separated or divorced parents to divide time between two homes (Kelly, 2007; Kreider, 2005). Children who live in two different homes may be exposed to different food environments and possibly, different levels of neighborhood deprivation. Moreover, children of single parent households are more likely to be exposed to higher levels of neighborhood disadvantage. Given data limitations, we were unable to

adjust for differential misclassification in neighborhood characteristics that may result from childhood exposure to multiple residential environments.

Whether there is an association between neighborhood food environment and childhood obesity remains unclear. Accurate measurement of neighborhood food environment is challenging given controversy in what is considered “healthy” versus “unhealthy” food environments. Even more difficult is operationalization of a food environment measure that is consistent over time. Our work is limited in that it mapped neighborhood food environment using data collected on healthy outlets in Delaware from 2009 to 2010. Although each outlet included in the Delaware Healthy Toolkit was contacted to confirm operation between January 1, 2004 and December 31, 2007, the DMBC delivery eligible timeframe and the number of food outlets that remained in business during the prospective evaluation of children is unknown. In an evaluation of the 182 businesses that were included in the analysis, 165 (90.5%) continued to operate in 2017.

In addition, we used straight-line distance between maternal residence and nearest food outlet as a proxy of food environment. Our measure does not consider travel time, nor does it account for mode of transportation (i.e. vehicle accessibility and/or use of public transportation) used by each maternal-child pair. In addition, our measure includes only the closest food outlet to each dyad and thereby likely fails to consider the full extent of food environment surrounding the women and their children. Similar to limitation in operationalizing neighborhood deprivation, our measure of food environment assumes residential stability of each maternal-child pair for the entirety of study follow-up. This assumption may result in

incorrect characterization food environment for dyads that moved during the study period.

BMI trajectories for Specific Aim 2 were calculated for all children with at least 2 well-child visits, regardless of the time interval between visits. As a result, trajectories could represent BMI change from 1 year to 5 years depending on well-child visit attendance. In addition, there was differential eligibility for follow-up based on birth cohort where children born in 2004 had the potential for 6 years of follow-up as compared to children born in 2007 who were eligible for only 3 years. While follow-up time and birth cohort were accounted for in multivariable models, duration of follow-up was directly associated with BMI trajectory category such that children with BMI decline had shorter follow-up time than their counterparts in the stable, steady gain and rapid gain categories. As a result, our measure of BMI trajectory may misclassify children, particularly those with shorter follow-up, and thereby is a limitation of our measure.

Further research, policy and practice implications

Nearly 1 in 5 school age children and youth in the United States is obese, reflecting a three-fold increase in obesity prevalence since the 1970's (Hales, 2017). Although levels appear to be stable over the past decade, the impact of obesity on the short and long-term health outcomes of children is significant.

It is unclear why levels of obesity have leveled over the past 10 years. Some postulate that stabilization in the prevalence of obesity in children may be attributable to the cumulative effect of public health efforts (i.e. school-based physical activity program) in

conjunction with economic interventions including taxation of carbonated beverages (Wabitsch, 2014). Others posit it is a result of effective community-based programs focused on educating consumers on healthy food options and bringing grocery stores into neighborhood historically considered “food deserts” (Gittlesohn, 2012; Karpyn, 2012; Taylor, 2015). While the plateau in prevalence is encouraging, and our findings support a direct association of maternal pre-pregnancy BMI and census-tract socioeconomic deprivation with obesity in children; the mechanisms underlying these associations are unclear.

A combination of intra- and extra-uterine environmental factors likely contribute to childhood obesity risk associated with maternal pre-pregnancy obesity. The results of a substantial body of literature on the obesogenic gestational environment suggest that there is an independent effect of maternal obesity on offspring BMI and cardiometabolic disease (Kim, 2015; Leddy, 2008; Tam, 2017). We did not find an association between gestational diabetes and obesity in children at 5-years, gestational diabetes was associated with steady gain in BMI trajectory in children from 2 to 8 years, but it was not associated with either decline or rapid gain. Further research is necessary to better understand the association between gestational diabetes and obesity risk in children.

Because gestation represents a potential critical period for offspring health, researchers have proposed pregnancy to be a window of opportunity for nutritional and/or physical activity interventions that may benefit the fetus (Adamo, 2012). Prenatal programs such as Nutrition in Pregnancy (NIP) housed in the Department of Obstetrics and Gynecology at the Johns Hopkins School of Medicine have attempted to integrate physical activity and nutrition interventions to mitigate

gestational weight gain in women with a first prenatal visit BMI ≥ 30 kg/m². In a prospective cohort study of women who participated in NIP between 2011 and 2014, there was no difference in infant growth when compared to a historical cohort of patients cared for by the same obstetrics practice (Gregory, 2016). Although there was no difference in early childhood growth trajectory, women who participated in the program were more likely to attend postpartum clinic visits and return to their pre-pregnancy weight. While preliminary data from this intervention did not show clear support of its effectiveness as a childhood obesity prevention program, the impact on women was notable.

Multiple clinical and public health programs similar to NIP exist across the country but few evaluate infant growth. The impact of prenatal interventions on offspring obesity was explicitly evaluated in two large-scale randomized controlled trials in the UK. The *Limiting Weight Gain in Overweight and Obese Women during Pregnancy to Improve Health Outcomes* (LIMIT) and *UK Pregnancies Better Eating and Activity Trial* (UPBEAT); these trials each enrolled over 1500 women to assess the efficacy of a prenatal provider-driven education program to provide evidence-based nutrition and lifestyle counseling to overweight and obese pregnant women (Dodd, 2014; Poston, 2015). Though both trials were appropriately powered to identify differences in maternal and infant outcomes, there were no differences in large-for-gestational age among infants born to mothers enrolled in the LIMIT or UPBEAT trials when compared to their non-intervention counterparts. Given the lack of findings, the authors concluded that even diet and activity interventions during pregnancy likely cannot have a meaningful impact on infant large-for-gestational age (Dodd, 2014; Poston, 2015). The authors concluded that maternal interventions to address both maternal

and child overweight and obesity are best managed through interventions along the life course.

In a 2017 Lancet Diabetes and Endocrinology series on maternal obesity, Hanson et al. (2017) reinforced the findings of LIMIT and UPBEAT and highlight the importance of obesity prevention programs over the life course. Specifically, they noted the importance of pre-gestational obesity prevention programs among reproductive age women to improve their health and the health of their offspring. Our work adds to knowledge of the association between maternal pre-pregnancy obesity and childhood obesity; however, studies had not been undertaken to assess whether obesity prevention programs targeting reproductive age women have any impact on obesity incidence in their offspring. Further research is necessary to clarify these associations.

Like the association between maternal pre-pregnancy BMI and weight status in children, the relation between neighborhood socioeconomic deprivation and BMI in children is complex, multifactorial and poorly understood. Extensive research has been conducted to evaluate the association between individual- and neighborhood-level socioeconomic disadvantage and obesity prevalence. While neighborhood socio-economic deprivation was associated with obesity but not BMI trajectory in children in our research, proximity to healthy food outlets was not associated with either childhood outcome. The association between neighborhood socioeconomic deprivation and BMI in early childhood may be related to a host of community factors associated with poverty including limited resources and lack of access to healthy, affordable foods; fewer opportunities for physical activity; greater exposure to marketing of obesity-promoting products; and, limited access to health care (FRAC, 2018).

Because low income populations often lack access to full-service grocery stores and farmers' markets, residents are often limited to food shopping at smaller outlets with fewer healthy options including fresh produce (Larson, 2009). Comprehensive reviews have identified that neighborhoods with better access to supermarkets and limited access to convenience stores tend to have reduced obesity prevalence among adults (Larson, 2019; Bell, 2013). Moreover, according to the United States Department of Agriculture, "vehicle access is perhaps the most important determinant of whether or not a family can access affordable and nutritious food" (Ver Ploeg, 2009). Because low-income urban families are less likely to have access to their own vehicle, they are more likely to rely on public transportation and/or food outlets within walking distance for food purchasing. Grocery shopping constraints limit how much can be carried and encourages high-frequency and low-quantity shopping. Moreover, this pattern of purchasing increases the stress and incentivizes purchasing products with longer shelf-lives (i.e. refined grains, preservative products), further preventing the purchase of fresh produce and protein.

Obesity rates in children are very high in Delaware with 17.2% of children 2 to 4 years with a BMI-for-age \geq 95th percentile and 13.4% of children age 3 to 23 months with \geq 2 standard deviations above the sex and age-specific median weight-for-length in 2014. Based on the 2010 census, 83.3% of Delaware residents live in urban tracts (2010 Census Urban and Rural Classification and Urban Area Criteria). Among our sample, 76.7% of women and children inhabited urban tracts. Given the rural/urban tract distribution in our population, it is likely that operationalizing proximity to healthy food outlet by a straight-line distance from residence to the closest outlet does not adequately

characterize food environment. Additional research is needed to better understand the interaction between census-tract density, transportation access and distance to healthy food outlet and childhood obesity and BMI trajectory.

While our work provides further support for a link between maternal pre-pregnancy BMI, neighborhood deprivation and child weight status, it does not discern the mechanism by which each are related to children's BMI. Our results advocate for continued investment in public health interventions focused on reproductive age women prior to conception to optimize women's and child health. In addition, our work supports the sustained attention to interventions focused within neighborhoods characterized by significant socioeconomic deprivation.

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6. Appendices

Appendix A: Maternal pre-pregnancy body mass index (BMI) by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood characteristics, aim 2 (n = 3862)

| Variable | N (%) | | | P |
|---|--------------|------------------------|------------------------|--------|
| | All | < 30 kg/m ² | ≥ 30 kg/m ² | |
| Maternal socio-demographic characteristics | | | | |
| Race | | | | |
| Caucasian/White | 1513 (39.18) | 1212 (80.11) | 301 (19.89) | <0.001 |
| Black/African-American | 1806 (46.76) | 1236 (68.44) | 570 (31.56) | |
| Hispanic, non-Caucasian | 418 (10.82) | 321 (76.79) | 97 (23.21) | |
| Asian | 78 (2.02) | 71 (91.03) | 7 (8.97) | |
| Other | 47 (1.22) | 38 (80.85) | 9 (19.15) | |
| Marital status | | | | |
| Single, widowed, divorced | 2185 (56.58) | 1567 (71.72) | 618 (28.28) | <0.001 |
| Married | 1677 (43.42) | 1311 (78.18) | 366 (21.82) | |
| Education | | | | |
| Less than high school | 905 (23.43) | 701 (77.46) | 204 (22.54) | <0.001 |
| High school graduate | 1363 (35.29) | 937 (68.75) | 426 (31.25) | |
| Any college | 1594 (41.27) | 1240 (77.79) | 354 (22.21) | |
| Insurance | | | | |
| Private | 1756 (45.47) | 1364 (77.68) | 392 (22.32) | <0.001 |
| Public | 2106 (54.53) | 1514 (71.89) | 592 (28.11) | |
| Parity | | | | |
| Nulliparous | 1338 (34.65) | 1066 (79.67) | 272 (20.33) | <0.001 |
| Multiparous | 2524 (65.35) | 1812 (71.79) | 712 (28.21) | |
| Age (years) | | | | |
| < 18 | 196 (5.08) | 178 (90.82) | 18 (9.18) | <0.001 |
| 18 - 34 | 3209 (83.09) | 2374 (73.98) | 835 (26.02) | |
| ≥ 35 | 457 (11.83) | 326 (71.33) | 131 (28.67) | |
| Maternal pre-pregnancy health characteristics | | | | |
| Chronic hypertension | | | | |
| No | 3720 (96.32) | 2818 (75.75) | 902 (24.25) | <0.001 |
| Yes | 142 (3.68) | 60 (42.25) | 82 (57.75) | |
| Diabetes mellitus | | | | |
| No | 3818 (98.86) | 2858 (74.86) | 960 (25.14) | <0.001 |
| Yes | 44 (1.14) | 20 (45.45) | 24 (54.55) | |
| Smoking history | | | | |
| No | 3049 (78.95) | 2293 (75.20) | 756 (24.80) | <0.059 |
| Yes | 813 (21.05) | 585 (71.96) | 228 (28.04) | |
| Pregnancy health characteristics | | | | |
| Gestational diabetes | | | | |
| No | 3623 (93.81) | 2764 (76.29) | 859 (23.71) | <0.001 |
| Yes | 239 (6.19) | 114 (47.70) | 125 (52.30) | |
| Pregnancy hypertensive disorder | | | | |
| No | 3578 (92.65) | 2708 (75.68) | 870 (24.32) | <0.001 |
| Yes | 284 (7.35) | 170 (59.86) | 114 (40.14) | |
| Birth weight (g) | | | | |
| < 1500 | 57 (1.48) | 39 (68.42) | 18 (31.58) | 0.011 |
| 1500 - 2499 | 306 (7.92) | 244 (79.74) | 62 (20.26) | |
| 2500 - 3999 | 3246 (84.05) | 2423 (74.65) | 823 (25.35) | |
| ≥ 4000 | 253 (6.55) | 172 (67.98) | 81 (32.02) | |
| Community characteristics | | | | |
| Census-tract deprivation | | | | |
| Minimal | 665 (17.22) | 570 (85.71) | 95 (14.29) | <0.001 |
| Mild | 579 (14.99) | 445 (76.86) | 134 (23.14) | |
| Moderate | 690 (17.87) | 501 (72.61) | 189 (27.39) | |
| High | 576 (14.91) | 411 (71.35) | 165 (28.65) | |
| Extreme | 1352 (35.01) | 951 (70.34) | 401 (29.66) | |
| Neighborhood food environment | | | | |
| < 0.5 miles | 1038 (26.88) | 761 (73.31) | 277 (26.69) | 0.297 |
| ≥ 0.5 miles | 2824 (73.12) | 2117 (74.96) | 707 (25.04) | |
| Cohort characteristics | | | | |
| Birth year | | | | |
| 2004 | 999 (25.87) | 733 (73.37) | 266 (26.63) | 0.812 |
| 2005 | 967 (25.04) | 723 (74.77) | 244 (25.23) | |

| | | | | |
|--------------------|--------------|--------------|-------------|-------|
| 2006 | 955 (24.73) | 716 (74.97) | 239 (25.03) | |
| 2007 | 941 (24.37) | 706 (75.03) | 235 (24.97) | |
| Follow-up (months) | | | | |
| ≤ 36 | 995 (25.76) | 739 (74.27) | 256 (25.73) | 0.549 |
| 37 - 60 | 1956 (50.65) | 1471 (75.20) | 485 (24.80) | |
| > 60 | 911 (23.59) | 668 (73.33) | 243 (26.67) | |

Appendix B: Neighborhood food environment by maternal socio-demographic, pre-pregnancy health, pregnancy health and census-tract deprivation, aim 2 (n = 3862)

| Variable | N (%) | <i>p</i> |
|----------|-------|----------|
|----------|-------|----------|

| | All | < 0.5 miles | ≥ 0.5 miles | |
|---|--------------|--------------|--------------|--------|
| Maternal socio-demographic characteristics | | | | |
| Race | | | | |
| Caucasian/White | 1513 (39.18) | 254 (16.79) | 1259 (83.21) | <0.001 |
| Black/African-American | 1806 (46.76) | 644 (35.66) | 1162 (64.34) | |
| Hispanic, non-Caucasian | 418 (10.82) | 119 (28.47) | 299 (71.53) | |
| Asian | 78 (2.02) | 11 (14.10) | 67 (85.90) | |
| Other | 47 (1.22) | 10 (21.28) | 37 (78.72) | |
| Marital status | | | | |
| Single, widowed, divorced | 2185 (56.58) | 767 (35.10) | 1418 (64.90) | <0.001 |
| Married | 1677 (43.42) | 271 (16.16) | 1406 (83.84) | |
| Education | | | | |
| Less than high school | 905 (23.43) | 306 (33.81) | 599 (66.19) | <0.001 |
| High school graduate | 1363 (35.29) | 429 (31.47) | 934 (68.53) | |
| Any college | 1594 (41.27) | 303 (19.01) | 1291 (80.99) | |
| Insurance | | | | |
| Private | 1756 (45.47) | 307 (17.48) | 1449 (82.52) | <0.001 |
| Public | 2106 (54.53) | 731 (34.71) | 1375 (65.29) | |
| Parity | | | | |
| Nulliparous | 1338 (34.65) | 350 (26.16) | 988 (73.84) | 0.463 |
| Multiparous | 2524 (65.35) | 688 (27.26) | 1836 (72.74) | |
| Age (years) | | | | |
| < 18 | 196 (5.08) | 70 (35.71) | 126 (64.29) | <0.001 |
| 18 – 34 | 3209 (83.09) | 885 (27.58) | 2324 (72.42) | |
| ≥ 35 | 457 (11.83) | 83 (18.16) | 374 (81.84) | |
| Maternal pre-pregnancy health characteristics | | | | |
| Pre-pregnancy BMI | | | | |
| < 30 kg/m ² | 2878 (74.52) | 761 (26.44) | 2117 (73.56) | 0.297 |
| ≥ 30 kg/m ² | 984 (25.48) | 277 (28.15) | 707 (71.85) | |
| Chronic hypertension | | | | |
| No | 3720 (96.32) | 1004 (26.99) | 2716 (73.01) | 0.422 |
| Yes | 142 (3.68) | 34 (23.94) | 108 (76.07) | |
| Diabetes mellitus | | | | |
| No | 3818 (98.86) | 1025 (26.85) | 2793 (73.15) | 0.688 |
| Yes | 44 (1.14) | 13 (29.55) | 31 (70.45) | |
| Smoking history | | | | |
| No | 3049 (78.95) | 780 (25.58) | 2269 (74.42) | <0.001 |
| Yes | 813 (21.05) | 258 (31.73) | 555 (68.27) | |
| Pregnancy health characteristics | | | | |
| Gestational diabetes | | | | |
| No | 3623 (93.81) | 985 (27.19) | 2638 (72.81) | 0.091 |
| Yes | 239 (6.19) | 53 (22.18) | 186 (77.82) | |
| Pregnancy hypertensive disorder | | | | |
| No | 3578 (92.65) | 956 (26.72) | 2622 (73.28) | 0.431 |
| Yes | 284 (7.35) | 82 (28.87) | 202 (71.13) | |
| Birth weight (g) | | | | |
| < 1500 | 57 (1.48) | 23 (40.35) | 34 (59.65) | 0.004 |
| 1500 – 2499 | 306 (7.92) | 99 (32.35) | 207 (67.65) | |
| 2500 – 3999 | 3246 (84.05) | 861 (26.52) | 2385 (73.48) | |
| ≥ 4000 | 253 (6.55) | 55 (21.74) | 198 (78.26) | |
| Community characteristics | | | | |
| Census-tract deprivation | | | | |
| Minimal | 665 (17.22) | 105 (15.79) | 560 (84.21) | <0.001 |
| Mild | 579 (14.99) | 85 (14.68) | 494 (85.32) | |
| Moderate | 690 (17.87) | 192 (27.83) | 498 (72.17) | |
| High | 576 (14.91) | 46 (7.99) | 530 (91.01) | |
| Extreme | 1352 (35.01) | 610 (45.12) | 742 (54.88) | |
| Cohort characteristics | | | | |
| Birth year | | | | |
| 2004 | 999 (25.87) | 744 (74.74) | 255 (25.53) | 0.454 |
| 2005 | 967 (25.04) | 715 (73.94) | 252 (26.06) | |
| 2006 | 955 (24.73) | 684 (71.62) | 271 (28.38) | |

| | | | | |
|--------------------|--------------|--------------|-------------|-------|
| 2007 | 941 (24.37) | 681 (72.37) | 260 (27.63) | |
| Follow-up (months) | | | | |
| ≤ 36 | 995 (25.76) | 693 (69.65) | 302 (30.35) | 0.009 |
| 37 – 60 | 1956 (50.65) | 1442 (73.72) | 514 (26.28) | |
| > 60 | 911 (23.59) | 689 (75.63) | 222 (24.37) | |

Appendix C: Census-tract deprivation by maternal socio-demographic, pre-pregnancy health, pregnancy health and neighborhood food environment, aim 2 (n = 3862)

| Variable | N (%) | | | | | | p |
|---|--------------|-------------|-------------|-------------|-------------|--------------|--------|
| | All | Minimal | Mild | Moderate | High | Extreme | |
| Maternal socio-demographic characteristics | | | | | | | |
| Race | | | | | | | |
| Caucasian/White | 1513 (39.18) | 497 (32.85) | 358 (26.55) | 334 (22.08) | 174 (11.50) | 150 (9.91) | <0.001 |
| Black/African-American | 1806 (46.76) | 98 (5.43) | 160 (8.86) | 262 (14.51) | 269 (14.89) | 1017 (56.31) | |
| Hispanic, non-Caucasian | 418 (10.82) | 27 (6.46) | 39 (9.33) | 67 (16.03) | 115 (27.51) | 170 (40.67) | |
| Asian | 78 (2.02) | 32 (41.03) | 16 (20.51) | 16 (16.03) | 7 (8.97) | 7 (8.97) | |
| Other | 47 (1.22) | 11 (23.40) | 6 (12.77) | 11 (23.40) | 11 (23.40) | 8 (17.02) | |
| Marital status | | | | | | | |
| Single, widowed, divorced | 2185 (56.58) | 128 (5.86) | 218 (9.98) | 331 (15.15) | 389 (17.80) | 1119 (51.21) | <0.001 |
| Married | 1677 (43.42) | 537 (32.02) | 361 (21.53) | 359 (21.41) | 187 (11.15) | 233 (13.89) | |
| Education | | | | | | | |
| Less than high school | 905 (23.43) | 36 (3.98) | 70 (7.73) | 126 (13.92) | 169 (18.67) | 504 (55.69) | <0.001 |
| High school graduate | 1363 (35.29) | 129 (9.46) | 188 (13.79) | 238 (17.46) | 226 (16.58) | 582 (42.70) | |
| Any college | 1594 (41.27) | 500 (31.37) | 321 (20.14) | 326 (20.45) | 181 (11.36) | 266 (16.69) | |
| Insurance | | | | | | | |
| Private | 1756 (45.47) | 532 (30.30) | 380 (21.64) | 383 (21.81) | 190 (10.82) | 271 (15.43) | <0.001 |
| Public | 2106 (54.53) | 133 (6.32) | 199 (9.45) | 307 (14.58) | 386 (18.33) | 1081 (51.33) | |
| Parity | | | | | | | |
| Nulliparous | 1338 (34.65) | 406 (16.09) | 371 (14.70) | 454 (17.99) | 372 (14.74) | 921 (36.49) | 0.031 |
| Multiparous | 2524 (65.35) | 259 (19.36) | 208 (15.55) | 236 (17.64) | 204 (15.25) | 431 (32.21) | |
| Age (years) | | | | | | | |
| < 18 | 196 (5.08) | 8 (4.08) | 16 (8.16) | 21 (10.71) | 32 (16.33) | 119 (60.71) | <0.001 |
| 18 - 34 | 3209 (83.09) | 510 (15.89) | 465 (14.49) | 582 (18.14) | 491 (15.30) | 1161 (36.18) | |
| ≥ 35 | 457 (11.83) | 147 (32.17) | 98 (21.44) | 87 (19.04) | 53 (11.60) | 72 (15.75) | |
| Maternal pre-pregnancy health characteristics | | | | | | | |
| Pre-pregnancy BMI | | | | | | | |
| < 30 kg/m ² | 2878 (74.52) | 570 (19.81) | 445 (15.46) | 501 (17.41) | 411 (14.28) | 951 (33.04) | <0.001 |
| ≥ 30 kg/m ² | 984 (25.48) | 95 (9.65) | 134 (13.62) | 189 (19.21) | 165 (16.77) | 401 (40.75) | |
| Chronic hypertension | | | | | | | |
| No | 3720 (96.32) | 650 (17.47) | 556 (14.95) | 667 (17.93) | 551 (14.81) | 1296 (34.84) | 0.222 |
| Yes | 142 (3.68) | 15 (10.56) | 23 (16.20) | 23 (16.20) | 25 (17.61) | 56 (39.44) | |
| Diabetes mellitus | | | | | | | |
| No | 3818 (98.86) | 658 (17.23) | 571 (14.96) | 680 (17.81) | 570 (14.93) | 1339 (35.07) | 0.851 |
| Yes | 44 (1.14) | 7 (15.91) | 8 (18.18) | 10 (22.73) | 6 (13.64) | 13 (29.55) | |

| | | | | | | | |
|----------------------------------|--------------|-------------|-------------|-------------|-------------|--------------|---------|
| Smoking history | | | | | | | |
| No | 3049 (78.95) | 591 (19.38) | 475 (15.58) | 557 (18.27) | 433 (14.20) | 993 (32.57) | <0.001 |
| Yes | 813 (21.05) | 74 (9.10) | 104 (12.79) | 133 (16.36) | 143 (17.59) | 359 (44.16) | |
| Pregnancy health characteristics | | | | | | | |
| Gestational diabetes | | | | | | | |
| No | 3623 (93.81) | 627 (17.31) | 546 (15.07) | 644 (17.78) | 527 (14.55) | 1279 (35.30) | 0.109 |
| Yes | 239 (6.19) | 38 (15.90) | 33 (13.81) | 46 (19.25) | 49 (20.50) | 73 (30.54) | |
| Pregnancy hypertensive disorder | | | | | | | |
| No | 3578 (92.65) | 634 (17.72) | 531 (14.84) | 641 (17.92) | 524 (14.65) | 1248 (34.88) | 0.033 |
| Yes | 284 (7.35) | 31 (10.92) | 48 (16.90) | 49 (17.25) | 52 (18.31) | 104 (36.62) | |
| Birth weight (g) | | | | | | | |
| < 1500 | 57 (1.48) | 5 (8.77) | 7 (12.28) | 10 (17.54) | 11 (19.30) | 24 (42.11) | <0.001 |
| 1500 - 2499 | 306 (7.92) | 26 (8.50) | 30 (9.80) | 59 (19.28) | 56 (18.30) | 135 (44.12) | |
| 2500 - 3999 | 3246 (84.05) | 577 (17.78) | 493 (15.19) | 566 (17.44) | 468 (14.42) | 1142 (35.18) | |
| ≥ 4000 | 253 (6.55) | 57 (22.53) | 49 (19.37) | 55 (21.74) | 41 (16.21) | 51 (20.16) | |
| Community characteristics | | | | | | | |
| Neighborhood food environment | | | | | | | |
| < 0.5 miles | 1038 (26.88) | 560 (19.83) | 494 (17.49) | 498 (17.63) | 530 (18.77) | 742 (26.27) | <0.001 |
| ≥ 0.5 miles | 2824 (73.12) | 105 (10.12) | 85 (8.19) | 192 (18.50) | 46 (4.43) | 610 (58.77) | |
| Cohort characteristics | | | | | | | |
| Birth year | | | | | | | |
| 2004 | 999 (25.87) | 182 (18.22) | 166 (16.62) | 167 (16.72) | 142 (14.21) | 342 (34.23) | 0.269 |
| 2005 | 967 (25.04) | 158 (16.34) | 158 (16.34) | 162 (16.75) | 154 (15.93) | 335 (34.64) | |
| 2006 | 955 (24.73) | 174 (18.22) | 125 (13.09) | 183 (19.16) | 130 (13.61) | 343 (35.92) | |
| 2007 | 941 (24.37) | 151 (16.05) | 130 (13.82) | 178 (18.92) | 150 (15.94) | 332 (35.28) | |
| Follow-up (months) | | | | | | | |
| ≤ 36 | 995 (25.76) | 134 (13.47) | 139 (13.97) | 176 (17.69) | 161 (16.18) | 385 (38.69) | < 0.001 |
| 37 - 60 | 1956 (50.65) | 386 (19.73) | 279 (14.26) | 352 (18.00) | 290 (14.83) | 649 (33.18) | |
| > 60 | 911 (23.59) | 145 (15.92) | 161 (17.67) | 162 (17.78) | 125 (13.72) | 318 (34.91) | |

JOHNS HOPKINS BLOOMBERG SCHOOL OF PUBLIC HEALTH
Curriculum Vitae

September 2018

MATTHEW AARON GOLDSHORE

Home Address:

2100 Walnut Street
Apartment 15L
Philadelphia, PA 19103

Office Address:

Surgery Education
4 Maloney
Hospital of the University of Pennsylvania
Philadelphia, PA 19104-4283

Education:

| | | |
|-------------------|-----|---|
| 08/2003 - 08/2007 | BS | University of Texas (Austin) Department of Chemistry & Biochemistry |
| 08/2007 - 08/2009 | MPH | George Washington University Department of Epidemiology |
| 08/2009 - 05/2016 | MD | George Washington University School of Medicine and Health Sciences |
| 08/2011 - 09/2018 | PhD | Johns Hopkins University (Public Health) Department of Population, Family and Reproductive Health Concentration: Perinatal Epidemiology |

Postgraduate Training:

| | |
|-------------------|--|
| 06/2016 - 06/2017 | Intern in General Surgery, Hospital of the University of Pennsylvania, Philadelphia, PA |
| 06/2017 - Present | Resident in General Surgery, Hospital of the University of Pennsylvania, Philadelphia, PA |

Faculty Appointments:

| | |
|-------------------|--|
| 08/2009 - Present | Adjunct Assistant Professor of Clinical |
|-------------------|--|

Research & Leadership
George Washington University,
School of Medicine and Health
Sciences

08/2009 - Present Adjunct Assistant Professor of
Education
Leadership
George Washington University,
Graduate School of Education

06/2016 - Present Assistant Instructor of Surgery
University of Pennsylvania,
Perelman School of Medicine

Licensure:

06/2016 - Present Pennsylvania Medical Training
License

06/2018 - Present Pennsylvania Unrestricted
Medical License

Honors and Awards:

2010 Gill Summer Scholarship Award
George Washington University

2013 Donald A. Cornley Scholarship
Johns Hopkins Bloomberg School
of Public Health

Memberships in Professional and Scientific Societies:

National Organizations

10/2007 - Present American Public Health
Association
Member

08/2009 - 06/2016 American Academy of Pediatrics
Medical Student Member

08/2014 - 06/2016 American College of Surgeons
Medical Student Member

07/2016 - Present American Academy of Pediatrics
Resident Member

07/2016 - Present American College of Surgeons
Resident Member

07/2017 - Present American Pediatric Surgical
Association
Resident Member

07/2018 - Present Academic Pediatric Association
Resident Member

State Organizations

10/2017 - Present Pennsylvania Medical Society
Member

Local Organizations

10/2018 - Present Philadelphia County Medical
Society
Member

Bibliography:

Original papers:

1. Glaser M, Winchell T, Plant P, Wilbright W, Kaiser M, Butler MK, Goldshore MA, Magnus M. Provider satisfaction and patient outcomes associated with a statewide prison telemedicine program in Louisiana. *Telemed J E Health*. 2010 May;16(4):472-9. doi: 10.1089/tmj.2009.0169. PubMed PMID: 20438385.
2. Rath B, Young EA, Harris A, Perrin K, Bronfin DR, Ratard R, Vandyke R, Goldshore MA, Magnus M. Adverse respiratory symptoms and environmental exposures among children and adolescents following Hurricane Katrina. *Public Health Rep*. 2011 Nov-Dec;126(6):853-60. PubMed PMID: 22043101; PubMed Central PMCID:PMC3185321.
3. Werner EF, Han CS, Savitz DA, Goldshore MA, Lipkind HS. Health outcomes for vaginal compared with cesarean delivery of appropriately grown preterm neonates. *Obstet Gynecol*. 2013 Jun;121(6):1195-200. doi: 10.1097/AOG.0b013e3182918a7e. PubMed PMID: 23812452.
4. Ehsanipoor RM, Jolley JA, Goldshore MA, Szymanski LM, Haydon ML, Gaffaney CL, Lagrew DC. The relationship between previous treatment for cervical dysplasia and preterm delivery in twin gestations. *J Matern Fetal Neonatal Med*. 2014 May;27(8):821-4. doi: 10.3109/14767058.2013.836178. Epub 2013 Sep 23. PubMed PMID: 23962130.
5. Goldshore MA, Solomon BS, Downs SM, Pan R, Minkovitz CS. Residency exposures and anticipated future involvement in community settings. *Acad Pediatr*. 2014 Jul-Aug;14(4):341-7. doi: 10.1016/j.acap.2014.02.011. Epub 2014 Jun 3. PubMed PMID: 24906986; PubMed Central PMCID: PMC4266696.

6. Minkovitz CS, Goldshore MA, Solomon BS, Guyer B, Grason H; Community Pediatrics Training Initiative Workgroup. Five-year follow-up of Community Pediatrics Training Initiative. *Pediatrics*. 2014 Jul;134(1):83-90. doi:10.1542/peds.2013-3357. PubMed PMID: 24982098; PubMed Central PMCID: PMC4067634.
7. DiPietro JA, Goldshore MA, Kivlighan KT, Pater HA, Costigan KA. The ups and downs of early mothering. *J Psychosom Obstet Gynaecol*. 2015 Apr 14:1-9. [Epub ahead of print] PubMed PMID: 25868806.
8. Gregory EF, **Goldshore MA**, Henderson JL, Weatherford RD, Showell NN. Infant growth following maternal participation in a gestational weight management intervention. *Childhood Obesity*. 2016 Apr 28. PubMed PMID: 27123956.
9. Gregory EF, **Goldshore MA**, Showell NN, Genies MC, Harding ME, Henderson JL. Parent and clinician perspectives on sustained behavior change after a prenatal obesity program: A qualitative study. *Childhood Obesity*. 2017 Apr 13. PubMed PMID: 27854496.

Accepted abstracts:

1. **Goldshore MA**, Henderson J, Ehsanipoor R, Baghlaf H, Werner E. (January 2013). Sensitivity and Specificity of ultrasound in the obese gravida. *Society of Maternal Fetal Medicine National Meeting*. [Presentation]
2. Lipkind H, Campbell K, Savitz D, Danilack V, **Goldshore MA**, Werner E. (January 2013). Obesity as an independent risk factor for severe maternal morbidity ('near-miss') during delivery hospitalization. *Society of Maternal Fetal Medicine National Meeting*. [Presentation]
3. Werner E, Ehsanipoor R, **Goldshore MA**, Baghlaf H, Burd I, Lipkind H (January 2013). Comparison of neonatal neurologic injury with forceps, vacuum and cesarean delivery. *Society of Maternal Fetal Medicine National Meeting*. [Poster]
4. Baghlaf H, **Goldshore MA**, Hueppchen N, Bienstock J, Werner E (January 2013). Neonatal complications with forceps assisted vaginal deliveries in a modern academic practice. *Society of Maternal Fetal Medicine National Meeting*. [Poster]
5. Werner EF, Han CS, Savitz DA, **Goldshore MA**, Lipkind HS (January 2013). Health outcomes for vaginal compared with cesarean delivery of appropriately grown preterm

neonates. *Society of Maternal Fetal Medicine National Meeting*. [Presentation]

6. **Goldshore MA**, Solomon BS, Downs SM, Pan R, Minkovitz CS. (February 2013). Residency exposures and anticipated future involvement in community activities. *Pediatric Academic Societies National Meeting*. [Poster]
7. Minkovitz CS, **Goldshore MA**, Grason H, Solomon BS, Guyer. (February 2013). Five Years Later: Involvement of Community Pediatrics Training Initiative Graduates in Community Activities. *Pediatric Academic Societies National Meeting*. [Presentation]
8. **Goldshore MA**, Augustyn MC, Gross S, Henderson JL, Werner EF and Paige D. (November 2013). Integrating obstetrical care and WIC nutritional services to address maternal obesity and postpartum weight retention: altering the life course trajectory. *American Public Health Association National Meeting*. [Presentation]
9. Henderson JL, **Goldshore MA**, Werner EW. (November 2013). An Innovative Care Model to Limit Gestational Weight Gain and Minimize Macrosomia in the Obese Gravida. *The Obesity Society: Obesity Week*. [Presentation]
10. Latimer K, **Goldshore MA**, Henderson JL, Brotzman H and Henderson JL. (February 2014). The utility of EKG screening in obese gravidas. *Society of Maternal-Fetal Medicine National Meeting*. [Poster]
11. Werner EF, **Goldshore MA** and Henderson, JL. (February 2014). A prenatal clinic dedicated to the care of obese gravidas. *Society of Maternal-Fetal Medicine National Meeting*. [Poster]
12. **Goldshore MA**, Werner EF and Henderson, JL. (March 2014). Effect of integrated obstetric and nutritional prenatal care on gestational weight gain (GWG) in obese gravidas. *International Association for the Study of Obesity Meeting*. [Poster]
13. Latimer, K, **Goldshore MA**, Henderson, J, Spitzer, J, Anastasio, H, & Werner, E (February 2015). Examining the utility of proteinuria screening in obese gravidas. *Society of Maternal Fetal Medicine National Meeting*. [Poster]
14. Anastasio, H, **Goldshore MA**, Werner, EF, Spitzer, J, Latimer, K, & Henderson, J. (February 2015). Thyroid function abnormalities among obese gravidas. *Society of Maternal Fetal Medicine National Meeting*. [Poster]

15. Gregory EF, **Goldshore MA**, Henderson JL, Weatherford RB, and Showell NN. (February 2015). Beyond Nutrition in Pregnancy: Pediatric follow-up of a prenatal weight management intervention. *Academic Pediatrics Association Region IV Meeting*. [Presentation]
16. Gregory EF, **Goldshore MA**, Henderson JL, Weatherford RB, and Showell NN. (February 2015). Early follow-up of infants whose mothers participated in a prenatal weight management program. *Johns Hopkins Primary Care Retreat*. [Presentation]
17. Gregory EF, **Goldshore MA**, Henderson JL, Weatherford RB, and Showell NN. (February 2015). Infant growth following participation of obese mothers in a prenatal weight management program." *Pediatric Academic Societies Annual Meeting*. [Poster]
18. Weatherford, RD, **Goldshore MA**, Weatherford, JS, Henderson JL. (May 2015). The Association between Obstructive Sleep Apnea Screening and Adverse Pregnancy Outcomes among Obese Gravidas. *European Congress on Obesity Meeting*. [Presentation]
19. Dumas RP, Chreiman KC, **Goldshore MA**, Seamon MJ, Cannon JW, Reilly PM, Christie J, Holena DN. (January 2018). Benchmarking emergency department thoracotomy: using trauma video to generate procedural norms. *Eastern Association of Trauma National Meeting*. [Presentation]
20. Swendiman RA, **Goldshore MA**, Blinman TA, Nance ML. (May 2018). Laparoscopic management in pediatric abdominal trauma: a national trauma data bank experience. *Western Pediatric Trauma Conference*. [Presentation]
21. Swendiman RA, Sharoky CE, **Goldshore MA**, Russel DKA, Nance ML. (May 2018). Acute neurosurgical needs in the pediatric trauma patient. *Western Pediatric Trauma Conference*. [Poster]